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THE DEVELOPMENT OF AMERICAN ARMOR-PLATE.

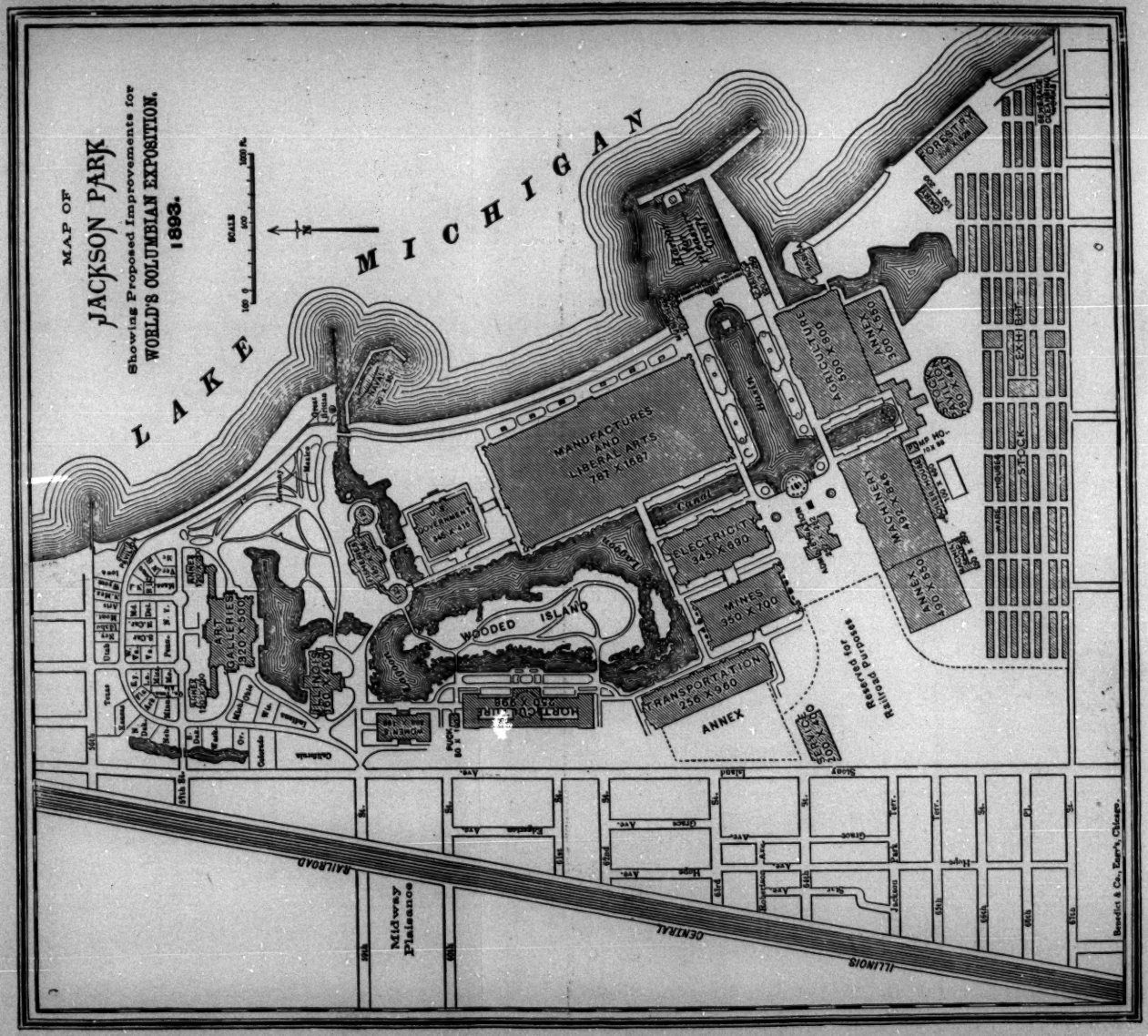
BY F. LYNWOOD GARRISON.

PREFATORY NOTE.

[It was the original intention of the author to contribute to the Franklin Institute the results of the recent armor-plate trials at Indian Head, in the form of a report. Owing, however, to the unavoidable delay in publishing the contribution, and to the fact that an excellent report of these trials has been published by the Chief of the Bureau of Ordnance of the Navy, such a report would appear unnecessary.

His aim has been, therefore, to prepare a paper giving a brief sketch of the development of armor-plate, together with the more important details of the official report.

The paper has been prepared from the standpoint of the metallurgist, rather than that of the military engineer.



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In the works of Very and Orde-Browne we have a complete and excellent history of the development and use of heavy armor-plates for naval and military purposes, but in these works the metallurgical side is but lightly touched upon.

Of course, much might be written upon the methods and appliances used in the manufacture of armor-plate, but such would seem more properly to belong to the province of metallurgy, than to a short paper on the present status of armor-plate in the United States. At the present time great interest is centred upon the use of the complex steel alloys and the methods used to harden them, and it is to these subjects more particularly that the author would call attention.

The detailed methods of producing such alloys as well as the several methods for quenching and tempering armor-plate are naturally kept secret by the steel manufacture.

The results of such operations are, of course, made public at the trials, and the possible deductions to be made therefrom are patent to every observing and thinking engineer.

The fact that the author has had exceptionally good opportunities to make such observations, he feels to be a sufficient excuse for publishing his views in the following paper.]

Sir Thomas Brassey, in his work on *The British Navy*, in speaking of armor and armor experiments,* says: "The defensive armor with which it has been customary of late to protect the heavy ships of modern fleets, may be considered with reference to its thickness, the material of which it is made and the method employed in its manufacture." Though ships' armor has been rarely subjected to the experience of real war, many questions referring to resisting power of the plates composing it have long been experimentally settled. "The general question is entering on a new stage; and there is now a *prima facie* case for inquiry, whether the increased power of armor-piercing guns and the augmented

* London, 1882, vol. ii, p. 3.

thickness of plates, as well as the introduction of new material into its composition, have not created a set of conditions which no longer support previously received theories of penetration and resistance."

These remarks were made in 1882, and now, in 1892, we find that with the introduction of nickel-steel and other alloyed* steels and with special processes for increasing the superficial hardness of armor-plates, the prediction is amply sustained.

One cannot but be impressed with the fact that with nearly every advance in the naval arts, the demands placed upon the metallurgist increase more and more; surely now, more than ever before, the arts of war must advance hand in hand with the arts of peace.

It seems eminently a prerogative of an institution like the Franklin Institute to take an active interest in the efforts which our Government is making to create a modern navy; surely there is no body of technical men in this country that can better appreciate such work or give it more aid.

In the armor-plates tried at Indian Head, October 31st and November 14th, the author ventures to say we have the most complicated metallurgical products ever dealt with by man. How little we know of that mysterious alloy called steel, how much less when it is further complicated by additions of nickel, copper, etc.!

In order that the author's remarks may be more intelligible to persons in civil life, he has deemed it proper to give a short sketch of the history of protecting ships of war by metallic armor. The subject is much more extensive than generally supposed, and its present advanced stage has only been reached by slow degrees and with a vast expenditure of money.

Although a number of schemes for the use of iron plates to protect batteries and ships were devised between the

* I use the word alloyed here in want of a better term; any steel is an alloy of iron and other elements, but it has only been with the introduction of this new class of steels that it has been necessary to use a compound word to indicate their distinctive characteristics. G.

years 1812 and 1855,* it was not until the Crimean war that any practical results were obtained.

During the action at Kinburn the French floating batteries, protected by four and one-half inch iron plates on seventeen inches of wood backing, were repeatedly hulled by the Russian guns, with no other result than the denting of the plates to the extent of one and one-half inches. In 1857, four-inch iron plates and two-inch steel plates, secured by bolts to two feet of oak, were tested at Woolwich with sixty-eight-pounders with unsatisfactory results. At 400

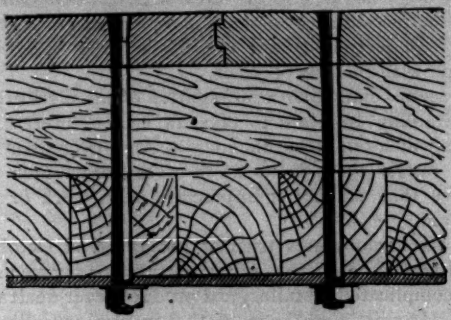

FIG. 1.—*Warrior* target.

yards the plates were badly broken up by both cast and wrought shot.†

In 1861, a target representing a section of the side of the new iron-clad ship *Warrior* (*Fig. 1*), was tried at Shoeburyness with 68-, 100- and 120-pounders, with the result that the plates were more or less cracked, but the ribs and inner skin uninjured. The *Warrior* target was constructed of four and one-half-inch solid iron plates, tongued-and-grooved as shown in *Fig. 1*. The design of the bolts should be noted, as they were vastly better than the system used on some of the earlier American iron-clads.

Ericsson's first battery, the famous *Monitor*, was protected

* See Holley's *Ordnance and Armor*, pp. 623–627.

† *Ibid.*, p. 630.

on the upper hull by six thicknesses of one-inch iron plates with one-half-inch inner skin; the deck by two layers of one-inch iron, and the turret by eight thicknesses of one-inch iron bolted one over the other with overlapping joints. The system of bolting can be fairly well understood from *Fig. 2*,* which was reproduced from a photograph taken shortly after the action with the *Merrimac*. In 1863, a target representing a section of the side of the iron-clad frigate *Bellerophon*, was tried in England. The armor (*Fig. 3*) consisted of six-inch rolled iron plates (not tongued-and-grooved as in the *Warrior* target), bolted to an oak frame with two and

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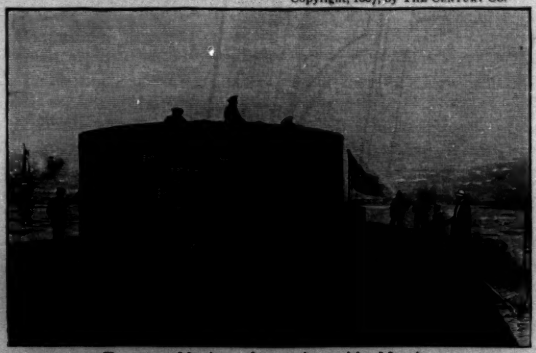

Fig. 2.—*Monitor* after action with *Merrimac*.

one-half and two and three-fourths-inch bolts. Each frame of the target was made of an angle iron $10 \times 3\frac{1}{2} \times \frac{1}{2}$ inch, and two of $3\frac{1}{2} \times 3\frac{1}{2} \times \frac{5}{8}$ inch, riveted together. To the frame thus formed a skin of two thicknesses of three-fourths-inch iron was riveted. On the outside of the skin four horizontal angle-iron stringers were attached, two under the upper armor-plate $9\frac{1}{2} \times 3\frac{1}{2} \times \frac{1}{2}$ inch, the broad flange being square to the skin, and not reaching out to the armor by half an inch. The other two are placed behind the lower plate $10 \times 3\frac{1}{2} \times \frac{1}{2}$ inch. The breadth of the broader flange being

* The author is indebted to the publishers of *The Century Magazine*, of New York, for the loan of this cut.

the same as the thickness of the backing, it reaches out to and comes in contact with the armor.*

This system made a very material improvement in the structural strength as well as a great addition to its power of resisting projectiles. From this period on, the thickness of iron armor and the wood backing rapidly increased; it seems to have reached its maximum in 1876 in the twenty-two inch iron plates tried at Spezzia during the autumn of that year.

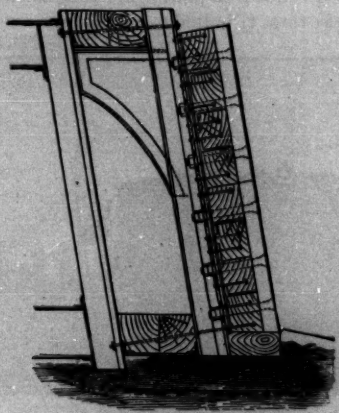

FIG. 3.—*Bellerophon* target.

Up to about 1879, wrought iron in various shapes was almost exclusively used for armor. Browne states that the chief value of wrought-iron plates is due to the fact that they do not transmit the shock to the bolts and adjacent parts of the structure. The blow is absorbed locally. They do not crack much if supported by proper backing, and may be penetrated with comparative ease.

In 1868, what was known as the Hughes hollow stringer (*Fig. 4*) was tried in the construction of the famous Millwall shield. The use of these hollow stringers was estimated by

* Holley, *Ordnance and Armor*, p. 761.

the Russian authorities to be equal to two inches of iron in increasing the defensive capacity. The arrangement of these stringers is shown in *Fig. 4;* they are placed horizontally and riveted to the side of the vessel, the hollow portion being filled with oak or teak.*

The following analyses of Russian and English iron armor-plates have been published by the Russian authorities.†

	Russian Plates.		
	I.	*II.*	*III.*
Carbon, { compound, =	0·07	0·06	0·07
Carbon, { graphitic, =	0·02	—	0·019
Silicon, =	0·12	0·20	0·15
Manganese, =	0·09	0·17	0·03
Phosphorus, =	0·12	0·36	0·04
Sulphur, =	0·02	0·038	trace
Arsenic, =	0·106	0·05	trace
Copper, =	0·02	—	0·07

	English Plates.		
	I.	*II.*	*III.*
Carbon, =	0·04	0·07	0·05
Silicon, =	0·117	0·20	—
Manganese, =	0·09	0·10	0·21
Phosphorus, =	0·165	0·17	0·23
Sulphur, =	0·01	trace	—

It might be well in this place briefly to consider what efforts have been made to use *cast iron* for defensive purposes.

Chilled cast iron is one of the hardest substances known in the arts, but what iron gains in hardness when in this form it loses in other qualities such as elasticity, ductility, etc. In order to possess a maximum of ballistic resistance an armor-plate must be not only very hard, but also elastic and ductile; these fundamental conditions have been thoroughly demonstrated by several trials of chilled cast-iron armor. Two firms in Europe have manufactured armor of this kind

* Hamersley's *Naval Encyclopædia*, 1884, p. 47.

† *Stahl und Eisen*, vol. v, p. 69, *Journal of the Iron and Steel Institute*, No. 1, 1886, pp. 316, 317.

to a considerable extent; Gruson, of Buckau, near Magdeburg, Prussia, and the St. Chamond Company, in France. During the year 1884, a number of armor-plates of chilled cast iron made by Gruson were tried at Buckau. Krupp steel projectiles were used with guns of various calibres. The results of these trials appear to have been considered satisfactory at the time, as were also the similar trials of St. Chamond during April, 1884.*

The result of trials several years later, however, led to both of these firms abandoning cast iron for armor-plate.

It appears from the total results of the trials, that for land defences (glacis armor chiefly), where the conditions were such that the angle of incidence of the projectile was

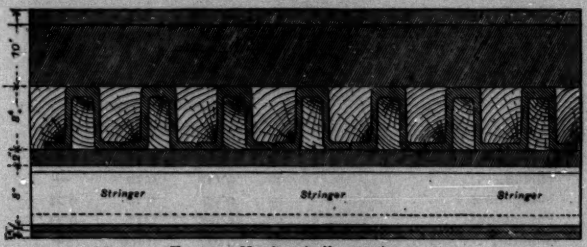

FIG. 4.—Hughes hollow stringer.

not great, chilled cast-iron plates made a good defence. In almost every case the projectiles were broken up.

The penetration was very slight, the surface at the points of impact being chipped off, and, as would be expected, the general destructive effect upon the shield was to crack it in various directions.

When iron is in a crystalline state its tendency to crack under the impact of a projectile is intensified when the latter strikes at a glancing angle, for under these conditions a second blow is delivered by the base of the projectile whilst the molecules of the iron are yet in violent vibration, caused by the impact of the point or ogival.

On the other hand, these plates can be made cheaply and

* *Engineering*, October 17, 1884, p. 374.

of great thickness for land defences, and owing to their hardness, rigidity and the rapidity with which they transmit shocks throughout their entire mass, they must be broken up bodily to be destroyed.

Although this system of armor cannot be considered to have been entirely successful in practice, its peculiarities both as regards construction and the results obtained, deserve more than passing notice.

Gruson's theory appeared to be that as cast iron could be moulded into any desired shape, plates or blocks with a curved profile could be used, which, whilst to a certain extent gaining in efficiency through the power of deflection, gained more by giving to the chilled crystallization a direction such as would put the body of the metal in the best condition for resistance to impact, and give mutual support to the parts of a plate even when the latter was fractured.*

His turrets were made ellipsoidal in shape, so as to make all parts mutually supporting. The ends of each block were slightly hollowed, so that when put in position zinc solder could run into the cavity thus formed by the close-fitting adjacent ends of the blocks, securing them together and thus avoiding all bolts or fastenings of any other description.

What mixture of pig irons Gruson uses to make these castings are not known outside of his works. It produces, however, peculiarly good results.

The fracture is a clear steely-white from the outer surface to about one-quarter of the depth of the casting, changing very gradually to a mottle for one-third farther, the remainder being a fine close-grained dark gray iron. There is no line of demarcation whatever between the chill and the soft iron, the one shading off almost imperceptibly into the other. The structure of the iron throughout appears as fine and close as in Whitworth's fluid-compressed steel, and entirely free from flaws.†

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* Very, p. 532, *Development of Armor for Naval Use. Proceedings of the U. S. Naval Inst.*, vol. ix. No. 3 [1883].

† Very, p. 533.

According to Barnaby,* satisfactory results were not obtained with the use of steel armor until the Spezzia trials of 1876. The plates then tested were 55 cm. (21·5 inches) thick, made at Creusot and such plates were subsequently used by the Italian Government to plate the *Dandolo* and *Duilio*. Three different systems of twenty-two inch armor were then subjected to strictly comparative tests, viz: English and French solid rolled iron plates; sandwiched plating of 10 x 11¼ inch iron, interspaced with wood, and one Creusot solid steel plate. The projectiles from a 100-ton (seventeen inch) Armstrong gun completely perforated and broke into fragments the iron plates; it perforated all of the sandwiched plates but failed completely to penetrate the steel one.

When steel for armor was first introduced to any practical extent, it was thought by some authorities that such plates need only be cast, not forged or rolled, but simply quenched in oil and annealed, thus dispensing with all expensive forging operations. This system, however, was soon abandoned for compound or solid forged steel plates. The rivalry between these latter two systems has been keen and active for a number of years, although the solid steel plates made at Creusot have repeatedly shown themselves to be superior to any form of compound armor.

A few years ago, thinking the armor problem about definitely solved by the use of compound armor, the British Government formally adopted it. This led to the expenditure of large sums of money in developing its manufacture in England, which, though active at present, will undoubtedly be discontinued before long.

Before leaving the subject of iron armor, it will be of interest briefly to review some of the metallurgical difficulties overcome in its development. "Between 1854 and 1858 armor-plate manufacture was limited in thickness to four and one-half inches, and but little dependence could be placed in regularity of quality even with this low thickness. The welding was imperfect, the best composition of ores to

* *Trans. of the Institution of Naval Architects*, 1879, p. 29.

produce desired results was not known, steely spots, burned metal, layers of scoria and scale, blow-holes and other imperfections were common and had to be accepted. At first the only rolls available for making armor were such as were used for boiler plates, and these were too light for the requirements. In consequence, the metal was shaped almost entirely under the hammer, which naturally would give results much more irregular than rolling. Time was required to design and erect the proper rolls, so that the real improvement in the condition of armor-plate cannot be said to have commenced much before 1859, and it is about this time that the first real increase in thickness of plates from four and one-half to four and three-fourths inches becomes noticeable."*

In the manufacture of the plates for the first French and English iron-clads much difficulty was experienced.

The worst trouble appears to have arisen from the prevalence of steely spots in the plates, which broke up the tools used in finishing and boring. The inspection was necessarily given wide limits. There was no experience to serve as a guide in this respect, so the manufacture was only carefully watched to gain the necessary knowledge, and the plates were only limited in tests for reception to the indications of specimens. In France, test plates were made of several different mixtures of iron, and were tested for strength in the tensile machine and under the hammer. In this way a standard was established, and the armor was all made of the same mixture. In the process of welding up the packets, the fag-ends were cut off and worked separately. They were then given the pulling and hammer tests to show the fracture, and if they failed to come up to the standard specimen the whole batch of plates was condemned. This was a very crude method of testing armor for reception, but was unavoidable at the start.†

For the sake of convenience we may divide steel armor under three heads, viz: compound, steel and alloyed steel.

* Very, p. 368.

† *Ibid.*, pp. 370, 371.

Compound Armor.—The process of manufacturing what is known as compound armor-plates was first patented in England by Alexander Wilson, of the Cyclops Works (Cammell & Co.), Sheffield, in 1876.*

In 1880, J. H. Ellis, of Sheffield, patented a somewhat similar process which has since been used by Brown & Co., of that place.†

The only difference between the two methods, as the author understands them, is that in the Wilson method a certain amount of low carbon steel ("ingot iron") is first cast on the hot wrought-iron back, and then a third layer of high carbon steel cast upon that, the wrought-iron plate being contained in a suitable cast-iron mould. By the Ellis method the low carbon ("ingot iron") steel plate forms part of the mould, the high carbon steel being cast in a space provided between the wrought-iron back and this plate.

Wilson specifies in his patent that the low carbon steel shall have a tensile strength of from 53,000 to 60,000 pounds per square inch, and that the high carbon steel shall contain from 1·25 to 1·5 per cent. carbon.

Ellis specifies for the low carbon plate 0·8 per cent. carbon and 0·8 per cent. manganese.

The principle in both methods appears to be, that the steel being at a much higher temperature than the iron plate, this excess of heat serves to bring its surface to a welding temperature. It is claimed the carbon in the steel carburizes the iron to a depth of from one-eighth to three-sixteenths of an inch, which, it is further claimed, constitutes an inseparable weld. As a matter of fact, however, the steel face is not always securely welded to the iron, and blisters of varying size occur at the joints. Even under the best conditions the steel face is liable to strip off the back, and where the projectiles penetrate, the holes are larger in the back than in front. This is strikingly illustrated in *Fig. 5*, which shows the Cammell compound plate at the Annapolis

* See British Patents, 4,746-1876; 3,472-1877; 2,130-1882; 15,476-1886; 5,727-1887; 9,392-1888.

† See British Patents, 3,629-1880; 1,051-1882.

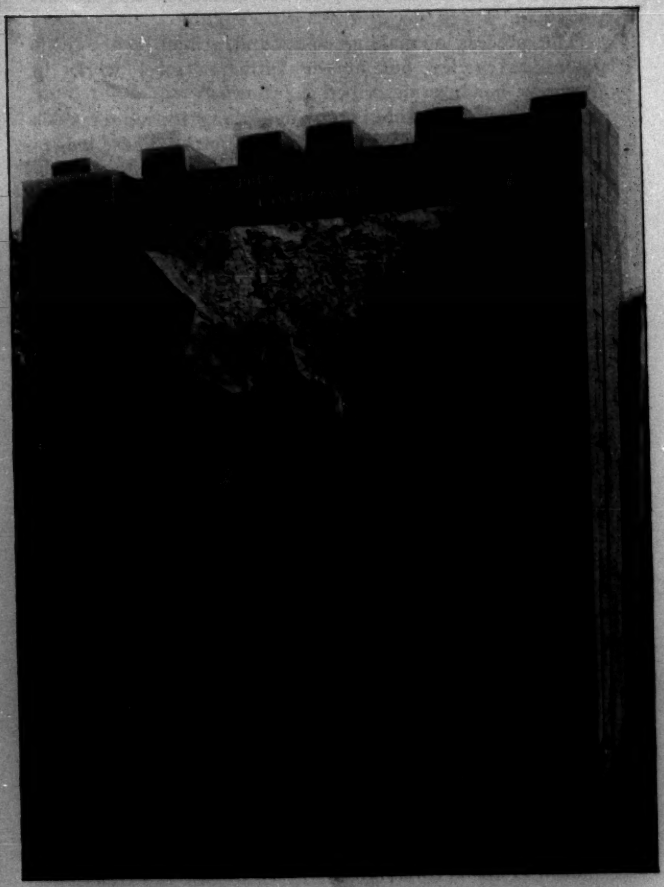

FIG. 5.—Cammell compound plate at Annapolis trials, 1890.

trials of 1890, after the firing of the fourth six-inch Holtzer projectile.

The process of making compound armor by the Ellis patent, as carried out at the Dillingen steel works in Germany, has been described as follows:*

A wrought-iron plate is provided along its longer sides with iron ledges secured to it by steel bolts. These ledges are provided with dovetailed grooves which receive a two-inch covering plate of ·45 per cent. carbon open-hearth steel. This soft steel cover, when rolled down to 0·8 inch in the finished plate, facilitates the subsequent bendings. By this means a five-inch space or mould is provided between the two plates into which the high carbon steel is cast, the two plates or mould being at a bright red heat at the time of the casting. When cool the ledges are removed, the whole reheated and rolled or forged to size.

The margin allowed for carbon in the inner steel stratum is one per cent. above or below standard; for phosphorus, ·025 per cent. provided the carbon is not above the standard, in which case no excess of phosphorus is allowed. Silicon in no case should exceed 0·4 per cent. When tested, a Cammell compound plate of 0·39 per cent. carbon in the steel face, did not prove superior to wrought iron of the same thickness; two others of ·45 and ·48 per cent. carbon were twelve and fifteen per cent. stronger; and a fourth one, with ·56 per cent. carbon gave excellent results. An analysis of one of the best compound English plates was as follows:†

	C.	*Si.*	*Mn.*	*P.*	*S.*	*Cu.*
Layer of steel, ...	·573	·173	·617	·054	·046	·026
Layer of iron, ...	·040	·217	·090	·165	·010	·016

The analyses given by Russian authorities of two similar plates are as follows:‡

							Tensile Strength.		Elongation.	
							In direction of fibre.	*Across the fibre.*	*In direction of fibre.*	*Across the fibre.*
	C.	*Si.*	*Mn.*	*P.*	*S.*	*Cu.*				
Layer of steel, .	0·66	0·10	0·93	0·03	0·05	0·02	93·650 lbs.	88·450 lbs.	1·17%	0·39%
Layer of steel, .	0·62	0·12	0·90	0·20	0·30	0·02	96·200 "	136·500 "	1·9%	1·8 %

* *Glaser's Annalen*, vol. x, p. 16. *Jour. of the Iron and Steel Inst.*, No. 1, 1882, p. 365.

† *Ibid.*, p. 367.

‡ *Stahl und Eisen*, vol. v, p. 133.

At Spezzia, in 1882, the steel faces of Brown's and Cammell's plates contained, respectively, 0·65 and 0·7 per cent., and Creusot steel plate about 0·45 per cent. carbon.*

It seems to the author useless to give any further particulars of the methods of making compound armor, as they are now practically obsolete, and in a few years will be undoubtedly replaced by better methods. In almost every case which has come to his notice within the last two years, compound armor has shown itself inferior to solid steel and alloyed steel plates.

As early as the Spezzia trials of November, 1882, compound plates showed themselves inferior to Schneider's (Creusot) steel plates in certain particulars.

"From an accurate examination of the cracks and the fractured sections, it was observed that in the compound plates the steel, and also the iron, showed rather a coarse grain; distinct strata of the metal imperfectly welded were noticed as well as cavities and traces of scoria. It was also noticed that the thickness of the steel stratum was not uniform, varying from six and one-fourth to four and three-fourths inches. It was noticed that in the weld of the two metals the iron presented a spongy appearance as if of inferior quality.

"In the Schneider plate a very fine grain was observed, uniform and compact, and showing a much greater molecular tenacity."†

It should be noted in this connection that the advantages of compound armor or, in fact, any face-hardened armor are, of course, more prominently demonstrated against oblique than against direct firing.

In most cases of armor-plate trials the gun has every advantage, the plate being subject to conditions which would seldom occur in actual warfare. It is rigidly fixed to a backing, the force of the impact of the projectiles must be

* Capt. Orde Browne, *Journal of the Iron and Steel Inst.*, No. 1, 1884, p. 117.

† Report of the Italian Commission. See Very, *Development of Armor for Naval Use. Proceedings of the U. S. Naval Institute*, vol. ix, No. 3, 1883, p. 502.

absorbed by a very small mass of material as compared with a ship's side, besides there is the absence of a structural flexibility or give, existing in the ship, which is no small factor in absorbing the force of the blow. Under the more recent trial conditions the point of impact is normal to the face of the plate, and the gun so close, that the projectile strikes with practically a muzzle energy.

Steel Armor.—The use of iron armor may be said to have ceased and the advent of steel armor to have taken place with the introduction of the 100-ton gun in 1876. At the celebrated Spezzia trials of that year the solid steel plates made by Schneider & Co., of Creusot, showed themselves superior in many particulars to the wrought-iron and sandwich plates subjected to the same tests. Such steel plates as the author has already mentioned, were subsequently adopted by the Italian Government. From this period up to within the last year or so the contest has been between compound and steel armor, the former being developed to its greatest extent in England and the latter in France.

It was not until about the time of the *Nettle* trials of May 19, 1888, that the English made any serious effort to catch up with the French in the manufacture of steel plates; these trials may therefore be considered as marking the beginning of the steel armor making era in England.

One of the plates then tried was made by Cammell and the other by Vickers. They were 8 x 6 feet x 10½ inches, and weighed 9·4 tons. Three a. p. 100-pound Holtzer and two Palliser chilled iron projectiles were fired at each plate —the range thirty feet and the striking energy 2,723 feet.

Cammell Plate.—Round 1 (Holtzer) penetrated 23·3 inches and broke in two, the head remaining in backing and base in plate.

Round 2 (Holtzer) penetrated 13·1 inches and lodged unbroken. Rounds 3 and 4 (Palliser), projectiles broken up, heads remaining in plate. Penetrations not given. Round 5, centre (Holtzer), penetrated 16 inches, lodged unbroken.

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* *The Year's Naval Progress*, p. 289. Office of *Naval Intelligence* Washington, D. C., July, 1891.

No through cracks at all developed. The plate showed, by the difference in the penetrations of the Holtzer projectiles, a decided lack of uniformity in the metal of which it was composed. The bulging on the back was very pronounced, and on the whole the plate cannot be considered equal to an average Creusot steel plate of the same or even an earlier date.

Vicker's Plate.—Round 1 (Holtzer), penetrated thirteen and one-half inches, and rebounded entire. Round 2 (Holtzer) penetrated thirteen inches and rebounded somewhat distorted. One radial through crack developed. Rounds 3 and 4 (Palliser), penetrations slight and projectiles broken up —no through cracks. Round 5, centre (Holtzer), penetrated thirteen inches and rebounded slightly distorted. One short through crack developed,

The penetrations give an evidence of great homogeneity of the metal. The elasticity of the plate was marked by the rebounding of the projectiles.

The general results were such as to lead to the belief that it was very similar in composition to the Creusot steel plates tried at Spezzia in 1876.

Since 1888 the Schneider (Creusot) steel plates have increased in efficiency, their maximum having probably been reached at the Annapolis and Ochta trials in 1890.* Some little progress seems also to have been made in England in the production of steel plates, Messrs. Vickers having received as a result of the *Nettle* trials, a large order from the Admiralty. The day of the steel plate, however, is past, as it will undoubtedly be superseded by the alloyed steel plate.

Lieut. Southerland, U.S.N., in his able review of "The Armor Question in 1891,"† very sensibly says: "The value of steel for armor protection can best be demonstrated by comparing it with the compound metal. With steel plates the face is hardened, but not to the same degree as the face of the compound. This disadvantage, however, even in plates of medium thickness, is more than compensated for

* *The Year's Naval Progress*, 1891, pp. 300 to 328.

† *Ibid.*, p. 332.

by the relatively greater hardness of the back, which tells more and more in favor of the steel as the plates increase in thickness.

"As a result of the softer face, projectiles of medium quality, although broken up by both metals, obtain a greater penetration in steel than in compound, as is evidenced by the French trials, but with a. p. (armor-piercing) projectiles, the resistance of the steel depending on its mass, penetration is less than in compound, where the hard face once overcome, the resistance of the soft back to penetration is but slight."

To the unprejudiced mind the advantages of steel over compound armor are manifest. It is not only more homogeneous than compound, but has the great advantage of being able to be cast into shapes which compound cannot.

As a result of the experiments of the Gavre Commission steel armor was found to possess a superior degree of toughness and elasticity. This property tends to distribute the projectile energy imparted to the plate more uniformly throughout its mass, thus decreasing its tendency to crack and break up, even though the projectile may attain a greater penetration than in the case of a compound plate.

The great inherent defect of solid steel armor-plate is the liability to through cracking. "If this through cracking causes the falling off of the fractured parts, either from succeeding shots or from the motion of the vessel in a seaway, steel would be useless for armor protection; but a careful study of armor trials is conclusive in showing that the system of bolting employed will hold fractured parts in place, unless the plate is excessively fractured by a greater number of blows than one can conceive of its receiving."*

A noticeable feature in steel plates is their tendency to form serrated cracks, as compared with the straight or curved lines of cracks in the compound. This enables fractured parts to dovetail into each other so as to cause them to remain in place, even when unsupported by

* *The Year's Naval Progress.* Office of *Naval Intelligence*, Washington, D.C., July, 1891, p. 332.

surrounding plates. It is evident that when badly cracked, the separated parts of steel plates will still offer considerable resistance to penetration. In the recent Annapolis trials, at the end of the fifth round of shots, each of the four separate parts of the cracked steel plate would still have resisted another projectile, while the compound plate, which presented a thickness of less than seven inches of wrought iron, would have been open to perforation by projectiles from as small a rapid-fire gun as the Hotchkiss fourteen pounder.

About the year 1887, one of the best British authorities, in speaking of steel armor, states that "Creusot steel is not usually as hard as the steel used in the face plates of compound armor, and is as a mass more rigid."†

"As compared with compound, steel armor admits the point of the shot at first with less resistance, but it does not yield at the point of impact even where badly backed, and is therefore less dependent on backing than compound armor. As the shot enters, it wedges and heaps up the metal around it, the plate coming forward and swelling at the point of impact and yielding by radiating cracks. It may be questioned if a case could be found of a concentric crack being made in steel armor. Nearly all cracks made extend through the metal, but by the employment of a large number of bolts the fragments may be held up, and considerable resisting power maintained after fracture. On the other hand very soft steel plates admit of perforation, and in their character resemble wrought iron more or less."‡

The action of the shot in wedging and heaping up the metal is much the same with nickel-steel plates—which in fact can only be regarded as steel plates strengthened and toughened by the addition of nickel.

Browne states§ that "steel plates are uncertain in their behavior and are liable to spontaneous fracture after tem-

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* *The Year's Naval Progress*, 1891, p. 333.

† C. Orde Browne, *Armor and its Attack by Artillery*, part II, p. 85, London, 1887.

‡ *Ibid.*, part II, p. 85.

§ *Ibid.*, part II, p. 99.

pering or after annealing." If such was the case eight or ten years ago, it was doubtless due to a want of knowledge and experience in the manufacture of such large masses of steel. This difficulty has probably been overcome, as we seldom hear of plates cracking spontaneously unless they have been unduly strained.

[*To be continued.*]

THE WORLD'S FAIR.

The World's Columbian exposition, at Chicago, will open on May 1, 1893. The following data give the reader an idea of its scope and magnitude and of its present status and prospects.

The Exposition is under the auspices of the United States Government. Its participants include not only the United States Government and the forty-four States and five Territories of the American Union, but also nearly every foreign government. Its international character is assured.

The foreign nations and colonies which thus far have determined to participate in the exposition, and the amounts of their appropriations, made or officially proposed, as far as information concerning them has been received at headquarters, are the following:

Argentine Republic,	$100,000
Austria,	149,100
Belgium,	
Bolivia,	100,000
Brazil,	600,000
China,	
Chile,	100,000
Colombia,	100,000
Costa Rica,	100,000
Denmark,	
Danish West Indies,	
Ecuador,	125,000
Egypt (informal),	
France,	400,000
Algeria,	
Germany,	214,200
Great Britain,	125,000
Barbadoes,	6,000
British Columbia,	
Bri ish Guiana,	25,000
British Honduras,	$7,500
Cape Colony,	25,000
Ceylon,	40,000
India,	
Jamaica,	20,000
Malta,	
Mashonaland,	
New South Wales,	
New Zealand,	
Queensland,	
South Australia,	
Tasmania,	
Trinidad,	15,000
Victoria,	
West Australia,	
Guatemala,	120,000
Hawaii,	
Hayti,	
Honduras,	20,000
Italy (informal),	

Erythria,		Salvador,	$12,000
Japan,	$630,675	San Domingo,	
Korea,		Siam,	
Madagascar,		Spain,	
Mexico,	750,000	Cuba,	25,000
Netherlands (informal),		Transvaal,	
Dutch Guiana,	10,000	Turkey,	
Dutch West Indies,	5,000	Uruguay,	
Nicaragua,	30,000	Venezuela,	
Orange Free State,		Total,	$4,004,565
Paraguay,	25,000		
Persia,		Thirty-nine nations.	
Peru,	125,000	Twenty-four colonies.	
Russia,			

Bolivia appropriated $10,000 for preliminary expenses, and authorized its President to draw on the regular diplomatic appropriation for any further sum needed, the whole amount estimated to be necessary being $100,000. Of Ecuador's $115,000, the city of Guayaquil furnishes $25,000. Paraguay has authorized its President to spend whatever sum may be necessary to have the country creditably represented. It is reported that $25,000 of expenditure is contemplated. Mexico has voted $50,000 for preliminary expenses. No doubt is felt that the balance of the $750,000 proposed will be forthcoming. It is assured that quite a number of the appropriations named above will be increased.

From information received at Exposition headquarters, it can be said to be almost assured that there will soon be added to the above list Norway and Sweden, Hungary, Switzerland, Canada and several others. At a low estimate the total of the appropriations of foreign nations will reach $5,000,000. Nearly all of the participating nations will erect buildings in the exposition grounds. Building sites have already been selected for Great Britain, Germany, Japan, Turkey, Mexico, Peru, Brazil, Ecuador, Colombia, Costa Rica, Guatemala and Chile. The buildings of foreign nations will present most varied contrasts in respect to size, architecture and adornment.

The United States Government has appropriated thus far $1,500,000, of which $400,000 was set apart for its building and $250,000, approximately, has been drawn for the cost of five sessions of the National Commission, two ses-

sions of the Board of Lady Managers, the salaries of the officers and employés of these two bodies, and the expenses of three special agents of the Treasury Department who were sent to Europe to explain to foreign commissions and governments the regulations of the department governing the importation of exhibits. A considerable portion of the remainder has been spent in preparation of the Government exhibit by the Board having the matter in charge. The Congress now in session is expected to appropriate a sum sufficient for the future expenses of the National Commission and Lady Managers, and the continued preparation of the Government exhibit, and also about $700,000 for the exposition awards and the payment of the awarding juries, as obligated by the Act of Congress creating the National Commission. The Government, as elsewhere stated, has been asked, also, to appropriate something for a District of Columbia exhibit, and $5,000,000 in general aid of the exposition.

Twenty-six States and two Territories, thus far, have made appropriations for their representation at the exposition, as follows:

Arizona,	$30,000	New Hampshire,	$25,000
California,	300,000	New Jersey,	20,000
Colorado,	100,000	New Mexico,	25,000
Delaware,	10,000	North Carolina,	25,000
Idaho,	20,000	North Dakota,	25,000
Illinois,	800,000	Ohio,	100,000
Indiana,	75,000	Pennsylvania,	300,000
Iowa,	50,000	Rhode Island,	25,000
Maine,	40,000	Vermont,	15,000
Massachusetts,	75,000	Washington,	100,000
Michigan,	100,000	West Virginia,	40,000
Minnesota,	30,000	Wisconsin,	65,000
Missouri,	150,000	Wyoming,	30,000
Montana,	50,000		
Nebraska,	50,000	Total,	$2,695,000

In several of these States the appropriations made are only preliminary, and will be largely increased. In Iowa, for example, the Executive Committee of the State Commission has prepared estimates aggregating $339,000, and will ask the Legislature to appropriate accordingly. Colorado, Maine, Massachusetts, Minnesota, New Jersey and West Virginia promise increased appropriations. In Colorado,

an additional $50,000, approximately, has been voted by the counties, and in Indiana about $10,000 has been raised by school pupils and teachers. In California, too, some of the counties are supplementing the State appropriation.

Nine States which, owing to constitutional restriction, or other prohibitive reason, made no World's Fair appropriation, have held State conventions and formed organizations of the stock-subscription sort for raising the amounts deemed necessary for creditable representation. These States, and the sums they are thus raising, are:

Alabama,	$50,000	Oregon,	$100,000
Arkansas,	100,000	South Dakota,	80,000
Florida,	100,000	Tennessee,	100,000
Georgia,	100,000	Texas,	300,000
Kansas,	100,000	Total,	$1,030,000

The legislatures of several States which have made no provision for representation are now in session, or soon will be. In Maryland, a bill for $100,000 is pending. In New York, a bill for $250,000 has been introduced, and a second bill for $500,000 is advocated by several influential organizations, which believe that sum necessary for creditable representation. Nearly all of the States and Territories that have not already made liberal appropriations, are expected to do so in time. It is reported that the Government will be asked to appropriate $50,000 for the representation of the District of Columbia, and perhaps something for an Alaska exhibit. The aggregate expenditure by the States and Territories is expected to reach $5,000,000.

Information concerning the State Buildings is yet quite incomplete, as but few of the plans have been approved. It is expected that nearly all will erect buildings as State headquarters and receptacles for collective exhibits illustrating their resources. Thus far, data for the buildings of twenty-two States, as projected, have been received at headquarters. These structures, for the most part, will be two stories in height; will average about 50 x 75 feet in dimensions, and will cost from $10,000 to $100,000 each.

The size and cost of the great exposition buildings are indicated in the following table:

Buildings.	Dimensions in Feet.	Area in Acres.	Cost.
Manufactures and Liberal Arts,	787 × 1687	30·5	$1,500,000
Administration,	262 × 262	1·6	435,000
Mines,	350 × 700	5·6	265,000
Electricity,	345 × 690	5·5	401,000
Transportation,	256 × 960	5·6	370,000
Transportation, Annex,	425 × 900	8·8	
Woman's,	199 × 388	1·8	138,000
Art Galleries,	320 × 500	3·7	670,000
Art Galleries, Annexes (2),	120 × 200	1·1	
Fisheries,	165 × 365	1·4	224,000
Fisheries, Annexes (2),	135 diameter.	·8	
Horticulture,	250 × 998	5·7	300,000
Horticulture, Green-houses (8),	24 × 100	·5	25,000
Machinery,	492 × 846	9·6	1,200,000
Machinery, Annex,	490 × 550	6·2	
Machinery, Power-house,	100 × 461	2·1	85,000
Machinery, Pumping Works,	77 × 84		
Machinery, Machine Shop,	146 × 250		
Agriculture,	500 × 800	9·2	618,000
Agriculture, Annex,	300 × 550	3·8	
Agriculture, Assembly Hall, etc.,	125 × 450	1·3	100,000
Forestry,	208 × 528	2·5	100,000
Saw Mill,	125 × 300	·9	35,000
Dairy,	100 × 200	·5	30,000
Live Stock (3),	65 × 200	·9	335,000
Live Stock, Pavilion,	280 × 440	2·8	
Live Stock, Sheds,	—	40·7	
Casino,	120 × 250	·7	210,000*
Music Hall,	120 × 250	·7	
		153·8	$7,041,000
U. S. Government,	345 × 415	3·3	400,000
U. S. Government, Imitation Battle-ship,	69·25 × 348	·3	100,000
Illinois State,	160 × 450	1·7	250,000
Illinois State, Wings (2),	—	·3	
		159·4	$7,791,000

* Including connecting peristyle.

The last three are being erected, the first two by the United States Government, and the third by the State of Illinois. The visitor, however, will naturally class them among the great exposition structures.

The exposition buildings, not including those of the Government and Illinois, have also a total gallery area of 45·9 acres, thus making their total floor space 199·7 acres. The Fine Arts building has 7,885 lineal feet, or 145,852 square feet of wall space.

All of the annexes will be scarcely less imposing and architecturally beautiful than the main buildings themselves. The live-stock sheds, which will cover an immense area as indicated, are to be constructed as inexpensively as possible without marring the general architectural effect. The power-houses, pumping works, etc., are to be exhibits in themselves, and so constructed as to be readily inspected by visitors. There will be several exposition buildings in addition to those named, but data concerning them are not yet fully determined. Among them will be a Press building, in which every possible convenience and accommodation for the press representatives of the world will be provided; and a reproduction of the Spanish convent, "La Rabida," in which a wonderfully complete collection of Columbus relics and allied exhibits will be gathered. The total cost of the exposition structures alone is estimated at $8,000,000.

The amount ($8,000,000) which the Exposition Company expects to expend upon buildings represents less than one-half of its total estimated expenditure for the great enterprise. Following are estimates of various other expenses prepared by the Ground and Buildings Committee:

Grading and filling, etc.,	$450,400
Landscape and gardening,	323,490
Viaducts and bridges,	125,000
Piers,	70,000
Waterway improvements,	225,000
Railways,	500,000
Steam plant,	800,000
Electricity,	1,500,000
Statuary on buildings,	200,000
Vases, lamps and posts,	50,000
Seating,	8,000
Water supply, sewerage, etc.,	600,000
Improvements of lake front,	200,000

World's Congress Auxiliary,	$200,000
Construction department expenses, fuel, etc.,	520,000
Organization and administration,	3,308,563
Operating expenses during Exposition,	1,550,000
	$10,530,453

Add to this the amount estimated to be necessary for buildings ($8,000,000), and the grand total sum to be expended by the Exposition Company stands at $18,530,453. This does not include, of course, the expenditure by the United States Government, the States of the Union, or foreign countries. Of this $18,530,453, about $17,000,000 must be paid out before the gates of the Exposition are thrown open to the public, on May 1, 1893. The total amount which the Exposition Company has paid out up to date, for all purposes, is $2,779,707. Owing to the present enormous demands of construction, the expenditure is now running at nearly $1,000,000 a month.

In view of the showing given above, a statement of the Exposition's resources will be found interesting in this connection.

RESOURCES.

Stock subscriptions,	$5,721,230
City of Chicago bonds,	5,000,000
Prospective gate receipts,	10,000,000
Concessions and privileges,	1,500,000
Salvage,	1,500,000
Interest on deposits,	33,452
Total,	$23,754,682

To the resources will be added future interest on bank deposits and future subscriptions to stock. New subscriptions are coming in daily, and the amount which will thus be realized is certain to be large, though how much it will be can now only be surmised. An increase of $200,000 from these sources is a safe estimate. On the other hand, some deduction must be made for delinquency in the payment of subscriptions to stock. Thus far, sixty per cent. of the subscribed amounts has been called for, and $3,433,800, or more than sixty per cent. has been actually paid in, quite a number of subscribers having voluntarily paid up in full without waiting for the successive calls. The subscribers number about 30,000. Among subscribers there have been nearly 500 deaths, and this, together with impoverishment,

etc., has caused thus far a delinquency in collections of between seven and eight per cent. of the amount due. This is less than was anticipated. Making a very liberal allowance for delinquencies, the net resources, as estimated, stand in round numbers at $23,350,000, or about $4,825,000 in excess of the total estimated necessary expenditure.

But of the resources the gate receipts, concessions and privileges, and salvage, representing a total of $13,000,000, are not only estimates but are necessarily prospective. They cannot be realized even in part until the exposition opens and is in progress. The salvage from the disposal of the buildings cannot, of course, be realized until after the fair closes. It follows that the resources available previous to the opening of the exposition, by which time, as explained above, $17,000,000, approximately, must be expended, are cut down to about $10,750,000. It will be seen that about $6,250,000 must be provided for in some manner. Accordingly, the United States Government may be asked to aid the exposition by taking a financial interest in it to the extent of $5,000,000. In view of the fact that the National Commission, representing the Government, in adopting the classification of exhibits, made the scope of the exposition so extensive that, as the Exposition Directory has found, it could not possibly be creditably fulfilled within the expenditure of the $10,000,000 which was at first deemed sufficient—and which Chicago has provided, according to promise—it is believed that Congress will consider it incumbent upon the Government, both in point of actual obligation and that the national honor may be maintained before the world, to provide the means for meeting the excess of expenditure which the action of its representative rendered necessary. With such assistance, to the extent of $5,000,000, the Exposition Company believes it will be able to meet all demands.

The actual erection of the exposition buildings began in June, 1891. Now all of them are being pushed rapidly towards completion. Already several are under roof. About 4,000 workmen are employed. Work proceeds day and night.

Woman's Building.—This is farthest advanced of all. It is roofed and almost completed exteriorly. Covered and adorned with "staff," it appears like a marble palace. The furnishing of the interior is proceeding.

Mines Building.—The framework is up, and finishing touches are being put on the iron and glass roof. The "staff" is being applied.

Electricity.—Framework completed up to gallery floor, and nearly all of the great steel trusses for the roof in place.

Horticulture.—The pavilions are up to the roof line. The west portion is roofed and windows are being placed. The iron work of the dome is being put in position.

Transportation.—Framework practically completed, as also roof sheathing over galleries. Clere-story trusses are being raised.

Administration.—Structural work of the four pavilions completed and exterior covering being applied. Iron work in place up to base of dome, 170 feet from ground.

Machinery Hall.—Floor and 6,000 supporting piers completed; superstructure going up, and foundation for annex being laid.

Agriculture.—Interior columns and gallery girders and joists in position, and the great iron columns supporting the roof being placed. Of the 7,000,000 feet of lumber which the building will contain, more than half is already utilized.

Manufactures and Liberal Arts.—The thirty and one-half acres of flooring are laid, and the superstructure is begun. The huge steel trusses for the roof, which together will contain more metal, by fifty per cent., than the Brooklyn bridge, will soon be raised.

Art Galleries.—Basement and floor are completed, and the brick walls have reached an average height of ten feet above the second floor. More than 5,000,000 brick are already laid.

Fisheries.—The gallery trusses of the main building are placed, and the iron framework of both pavilions is completed.

Forestry.—This is about three-fourths finished, and will be occupied by the model makers until spring, when the outside rustic work will be put on, and the temporary roof will be replaced by a thatched one.

Dairy.—All the columns are up to the roof line, and the gallery floor is being laid.

Work on the Illinois State building and on the United States Government building is being pushed rapidly. The imitation battle-ship is completed to the deck level.

Insurance is placed and increased on the buildings as their construction proceeds. The amount now carried is above $1,000,000. During the exposition, it is estimated not less than $150,000,000 or $200,000,000 of insurance will be carried on the buildings and exhibits.

All possible precautions are taken against fire. The exposition grounds are already provided with a full equipment of fire engines and apparatus.

In the construction of the buildings about 60,000,000 feet of lumber and 18,000 tons of steel and iron will be used. In their adornment will be utilized nearly 84,000 pieces of ornamental "staff" work, of which about one-third are already completed.

To supply the exposition buildings and grounds with water two plants are being put in, one with capacity of 24,000,000 gallons a day, and the other of 40,000,000 gallons. Thus 64,000,000 gallons a day will be available. The pumping works and all of the great machinery furnishing power to the exposition will be open to the inspection of visitors.

A system for drainage, believed to be adequate and perfect, has been adopted. Perfect sewerage, too, is planned. All refuse from the *cafés* and kitchens, and from the lavatories and closets, of which 6,500 will be constructed at an expense of some $450,000, will be received by injectors, and forced by compressed air through underground pipes into four huge tanks, where it will be treated chemically and rendered entirely inoffensive. Work upon these systems is progressing.

Plans adopted for lighting the buildings and grounds

provide for 138,218 electric lamps, of which 6,766 are to be arc lamps of 2,000 candle-power each, and 131,452 incandescent, sixteen candle-power each. The electric lighting will cost something like $1,500,000 and will be ten times as extensive as was employed at the Paris exposition. The light and motive plant at the exposition, it is estimated, will require 26,000 horse-power, of which 22,000 will be required for the electric plant.

Transportation to and from the exposition, both for visitors and exhibits, will be as perfect as it is possible to make it, both in the matter of facilities and rates. Greatly reduced rates on all railroads and some of the steamship lines will prevail. Definite arrangements are yet to be perfected. Much attention is being given to the question of furnishing abundant facilities for reaching the grounds from all parts of Chicago, and it can be asserted that existing means, already extensive, will be increased so that a maximum of 400,000 a day can be carried to and from the grounds. For the transportation of exhibits, arrangements have already been made with nearly 500 railway and steamship lines, including all of the trunk railroads and more important lines in the United States. Of these transportation lines, 417 have agreed to charge regular tariff rates on exhibits to the exposition, and to return them to starting points free of charge, provided their ownership remains unchanged. Thirty-seven have agreed to charge half regular rates both ways, and thirty-three have promised to transport them free both to and from the exposition. The Atlantic Transport Line of Steamers, which runs freight steamships between London and New York, Philadelphia and Baltimore, will make no charge on exhibits in either direction, except on such as, owing to their excessive size or weight, require extra help in their handling. In such cases only the expense of the extra help will be charged. Foreign exhibits will be admitted free of all duty. Such exhibits, however, if sold in this country, will be subject to payment of regular customs duties.

The World's Congress Auxiliary.—This is organized to provide for the presentation, by papers, addresses and discussion,

of the mental and moral status and achievements of the human race. Under its auspices, a series of congresses will be held in Chicago during the progress of the exposition, in which, it is already assured, will participate a great many of the ablest living representatives in the various fields of intellectual effort and moral endeavor. The Auxiliary embraces between fifteen and twenty main departments, such as Literature, Government, Education, Music, Science, Art, Engineering, etc., in each of which are subdivisions. A programme is being arranged for congresses in each of these departments and divisions, in which specialists and advanced thinkers may participate in discussing the vital and important questions, and presenting the best and latest achievements of the human mind in each. During the exposition the Auxiliary will have the use of a magnificent permanent Art Palace, which the Chicago Art Institute, aided by the Exposition Directory, is about erecting on the lake front. This will have two large audience rooms, each of 3,500 capacity, and from twenty to thirty smaller rooms, of capacity ranging from 300 to 750. The great auditorium will also be utilized for the larger congresses, and numerous other halls are available when required. Each congress will be supervised by a committee of persons actively interested in its particular field, acceptance of such responsibility having already been given. The prospects are that fully 100 congresses altogether will be held. It is the intention to publish their proceedings in enduring form. Detailed information concerning the Auxiliary, or any of its departments or divisions, can be obtained of its President, Charles C. Bonney.

The participation of women in the exposition promises to be one of its most interesting as well as novel features. With a commodious and imposing building, designed by a young lady architect, and with an abundance of money, and with full recognition, indorsement, and aid by the United States Government and the Exposition Directory, the women have an opportunity of showing, in most signal manner, the condition of their sex throughout the world; what are the achievements of woman in the various branches

of human endeavor, and what is her adaptability to different occupations and lines of industrial and charitable work. Under the direction of the Board's President—Mrs. Potter Palmer—the work of organization, and of enlisting the interest of women throughout the United States and in foreign countries, has progressed to a most satisfactory stage.

Jackson Park and Midway Plaisance—the Exposition site—are in the southeastern part of Chicago, and embrace 664 acres, with a frontage of about a mile and a half on Lake Michigan. Forty-five miles of boulevard connect the site with the general park system of Chicago, which embraces fifteen or more parks, aggregating 2,000 acres.

Half a million dollars has already been expended in grading Jackson Park and dredging extensive waterways throughout it. Hundreds of thousands are yet to be spent for landscape gardening, fountains, statuary, pleasure boats, etc. A number of observation towers, from which excellent views of the buildings and grounds can be obtained, will be erected in different parts of the Park.

According to present plans fully 150 restaurants and *cafés* will be in operation in the various buildings and about the grounds. These will be conveniently distributed, and will have an estimated aggregate seating capacity of 6,000 or 8,000.

Midway Plaisance, connecting Jackson Park with Washington Park, will be occupied throughout its entire length by special Exposition features largely of a foreign character, such as the "Bazaar of All Nations," "Street in Cairo," "Street in Constantinople," "Moorish Palace," "Maori Village," etc., to which concessions have been granted, and which, in their production, will represent the expenditure of hundreds of thousands of dollars. Panoramas, cycloramas, the sliding railway, etc., will also be located there.

A single entrance fee, probably fifty cents, will entitle visitors to see the entire exposition proper. The special attractions on Midway Plaisance will make a moderate additional charge.

The hotel accommodations of Chicago, already very

extensive, are being augmented by the erection of fully twenty new hotels, some of which are very large. Two million dollars or more are to be spent by the city and the Park Commissioners, in putting the streets, parks, etc., in presentable condition against the influx of visitors.

It may be said to be assured that the exhibits at the exposition will cover a wider range and be far more numerous than were ever before gathered together. They will present a picture of the condition and industrial progress of mankind in every quarter of the world, and of its achievements in every branch of the sciences and arts. The exposition classification embraces twelve departments, 176 groups, and 967 classes. The application for space by intending exhibitors in the United States alone, numbered 2,082 on January 1st. The number at the Philadelphia Centennial on corresponding date was 864. Applications from foreign exhibitors are reported very numerous and rapidly increasing. It seems assured that the exhibitors will outnumber those at any previous world's fair. The allotment of space will be made about June. The reception of exhibits will begin November 1, 1892, and continue until April 10, 1893. No charge will be made for space for exhibits.

The exposition buildings, as required by Act of Congress, will be dedicated "with appropriate ceremonies" on October 12, 1892, the 400th anniversary of the discovery of America by Columbus. The exercises will occupy three days, beginning on the 11th and closing on the 13th with a grand dedication ball. The committee having the matter in charge has planned to make the ceremonies most impressive in character. Something like $300,000 will be spent to secure this end. The President of the United States and his Cabinet, the Senate and House of Representatives, the Governors of the several States with their staffs, and representatives of all foreign nations will be invited to be present. The mobilization of 10,000 militia and several thousand regulars is planned, as is also an imposing civic and industrial display. In the evenings there will be a magnificent display of fireworks, and in the Park waterways a pageant

of symbolical floats, representing the "Procession of the Centuries." In the dedicatory exercises on the 12th, the complete buildings will be tendered by the President of the Exposition to the National Commission. President T. W. Palmer will accept them on behalf of that body and will at once present them to the President of the United States, who will fittingly respond. The dedicatory oration will follow. Much attention is being given to the musical portion of the programme. This will include a dedicatory ode and orchestra marches written for the occasion. These and other numbers, including "America" and "Star Spangled Banner," will be rendered with full choral and orchestral accompaniment.

In April, 1893, a grand international naval review, preliminary to the opening of the exposition, as provided for by Act of Congress, will be held in New York harbor. Arrangements for this are now being made.

The exposition will open its doors to the public on May 1, 1893, and close them on October 30th, of the same year.

A PRACTICAL CONSIDERATION OF COMPRESSED AIR.

By Wm. L. Saunders, C.E.

[*A lecture delivered before the Franklin Institute, December 11, 1891.*]

In an address recently delivered before this Institute and published in the *Journal* for July, 1891, Dr. Coleman Sellers, in referring to the utilization of the power at Niagara Falls, used the following words:

"You may wonder why compressed air is thought of at all for transmission, as you have known in America that it has been thought to be a very wasteful manner of transmitting power, but the recent improvements that have been made in compressors have very much changed the condition of that mode of transmission, and the fact that so much gain is possible by reheating the air indicates a cheap power which can be transmitted long distances with economy."

This concise and truthful statement has been selected as a text for what I have to say on the subject of compressed air, because, in the first place, it calls attention to the very general impression which exists in America as to the "very wasteful manner," by which power is transmitted by compressed air, and it suggests the true solution of the problem, which is in the direction of improvements in air compressors and reheating the air.

Compressed air, though one of the oldest of the sciences, is in its development and use one of the youngest. Hero of Alexandria, a century before Christ, experimented and wrote upon "Pneumatics," calling special attention to the influence of heat in expanding and contracting air, and Prof. Thurston has given us an account of an invention which was put into practical use by Hero, by which the opening and closing of temple doors was effected by the alternate rarefaction and condensation of air which was brought in contact with heated and cooled surfaces of altar tops. Yet the science of pneumatics played no important part in industrial progress until scarcely more than a century ago it came into general use for diving-bells, and later on it was applied by Brunel to caisson work.

The use of compressed air in America has been confined almost exclusively to mining, tunnelling, bridge building and work in a confined space for which no other power was available. The question has not been one of economy of power, but of durability of apparatus, low first cost, light weight, economy of space and general availability for the purpose. Dry, pure air delivered at a sufficient pressure by a machine which could be depended upon, has been the controlling consideration. Such a condition of things offers no stimulus in the line of fuel economy, and it is only during recent years and since the use of compressed air has been extended to work above ground, that the percentage of power delivered in proportion to that consumed has been recognized as a thing of great importance in the science.

Since the necessity of economy in the production and use of compressed air power became recognized, the question has been considered and the science developed by two

distinct classes of men, the theorists and the practical men. The theorists are the professors and engineers whose skill as mathematicians has enabled them to indulge in such an array of figures, and to produce so many cobwebs in diagrams relating to the expansion and contraction of gases, and bearing upon the intricate laws of thermodynamics, that the more practical engineers have avoided the subject as one which belonged only to specialists. The practical men have been left to themselves to make improvements, and have made slow progress because they did not possess the proper theoretical knowledge. In other words, that true combination of theory and practice which leads to the best results has been wanting among pneumatic engineers.

The whole question of compressed air economy is based upon

(1) Economy of production;

(2) Economy of use.

Transmission calls for but little consideration. This statement will doubtless surprise many who look upon the losses suffered in the use of compressed air as due largely to transmission, and no better evidence is needed of the obscurity of the science, even among engineers, than this fact. There is not a properly designed compressed air installation in operation to-day that loses over five per cent. by transmission alone. The question is altogether one of the size of pipe, and if the pipe is large enough the friction loss is a small item. It is undoubtedly true that there are places where a conduit has been laid for a certain volume of air, and where the supply has been increased without increasing the size of the conduit, the result of this being that more air is forced through the pipe than its sectional diameter will admit economically; hence the velocity of flow is increased, and as the friction is in direct proportion to the velocity, the loss of power is also increased. The largest compressed air power plant in America is that at the Chapin Mines in Michigan, where the power is generated at Quinnesec Falls, and transmitted three miles. This is not an economical plant, but the loss of pressure as shown by the

gauge is only two pounds, and this is the loss which may be laid strictly to transmission. I recently visited the Jeddo Tunnel, near Hazelton, Pa., where compressed air at sixty pounds pressure is conveyed 10,860 feet. They told me that they had tried the gauges on both ends of the line, and had found no difference whatever in pressure, but that the gauges had been sent to the shops for repairs as they were convinced that "something was wrong." The result was not changed when the gauges had been "repaired," and it was evident that this apparently perfect economy of transmission was due to the fact, that a large pipe (five and three-fourths inches in diameter) was used to convey so small a volume of air, that the velocity in the pipes produced so small a friction loss that it could not be recorded on the gauge.

A question commonly asked is, How much power is lost in using compressed air? I usually reply, fifty per cent., because a proper qualification of the question will result in figures in one case below and in the other above fifty per cent. If compressed air is produced by the best modern air compressor, and used by the best modern engine *immediately at the compressor*, the loss is only that which is suffered when using any like engine, and is confined in its greatest extent to the question of engine friction, and is only to a small degree influenced by shrinkage of volume through radiation, clearance loss, leakage, etc. In such cases the loss varies between ten and twenty-five per cent., but such cases are rare, because it would obviously be more economical to use the steam direct.

The usual conditions of compressed air use are those where the air engine is situated from 1,000 feet to several miles from the compressor. In most cases the distance is so great that the compressed air enters the engine at a temperature equal to that at which it entered the compressor. Were it possible to produce compressed air isothermally; that is, without increase of temperature during compression, the service would be economical even at low temperatures, but isothermal compression has never been realized, and the heat produced during compression (which is the exact

equivalent of the power applied) is suffered to increase the pressure, and hence to increase the resistance to compression, without a relative increase of volume. Hot air under pressure is discharged into a receiver, and the gauge indicates a pressure of (say) sixty pounds, which is equal to that recorded by the gauge 10,000 feet away, yet it is a false indication as affecting the question of power, because every cubic foot of sixty pounds air at the compressor is less in weight than an equal volume of equal pressure air at the engine, in exact proportion to the difference in temperature. The result of this is that an air engine which uses (say) 100 cubic feet of sixty pounds air per minute at the temperature of the surrounding atmosphere, really uses about 150 cubic feet of sixty pounds air at the receiver temperature. All this is very important in looking for a remedy for compressed air losses, because it points to the influence of heat upon air, and the importance of reheating compressed air.

The loss of power in common practice where compressed air is used to drive machinery in mines and tunnels, is about seventy per cent. I refer to cases where common American air compressors are used, and where the air is transmitted far enough to lose its heat of compression and is exhausted without reheating.

In the best practice, with the best air compressors, and without reheating, the loss is about sixty per cent.

These losses may be reduced to a point as low as twenty per cent. by combining the best systems of reheating with the best air compressors. In France, England and Germany there have been erected during recent years large compressed air installations. In Paris about 25,000 horsepower is transmitted over the city and is used to drive engines and for many other purposes. With a less efficient production than our American system, they have advanced beyond us in the use of compressed air. Reheating has been put into general use, while here in America the improvements have been more conspicuous in the air compressor. Prof. Kennedy, whose elaborate report on the Paris plant is accepted as an authority, uses the following words:

"Summarizing now the whole matter as regards effi

ciency, it may be said that the result of my detailed investigations is to show that the compressed air transmission system in Paris is now being carried on, on a large commercial scale, in such a fashion that a small motor four miles away from the central station can indicate in round numbers ten horse-power, for twenty horse-power at the station itself, allowing for the value of the coke used in heating the air."

Prof. Kennedy concludes his report by saying, "Nothing, indeed, can be easier (as was evident on the recent visit of the Institution of Mechanical Engineers to St. Fargeau) than to point out various weak points in the arrangements

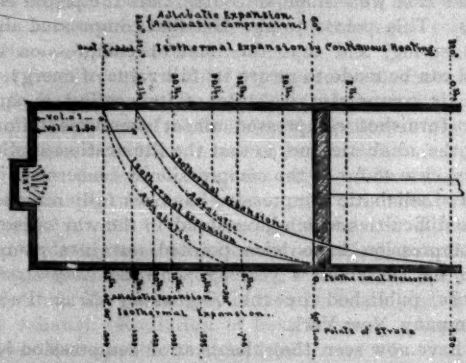


FIG. 1.

adopted." We may reasonably expect to add to this fifty per cent. efficiency attained in Paris by an installation which combines the American compound condensing Corliss air compressor with an efficient and economical reheating apparatus and Corliss or other economical engines.

The whole science of the production and use of compressed air can be best understood by a simple practical illustration.

Fig. 1 is an open cylinder which may be made to illustrate at the same time the air compressor and the air engine. The piston at the point shown is supposed to confine a volume of free air in the cylinder and at a tempera-

ture of 60°. Let it be pressed down until it reaches the point indicated by forty-five pounds at the left, and the pressure will follow the dotted line marked "Adiabatic." This is, of course, assuming that the heat, which is invariably produced by compression, is suffered to remain in the air and to influence the pressure. We here have a confined volume of compressed air at a pressure of forty-five pounds and a temperature of 320°. Let there be no absorption of heat and the piston if released will return to the starting point, the pressure following exactly the line indicated during compression and the temperature returning to 60°. In such a case we assume, of course, that the piston is frictionless. This points to the fact that compressed air is a perfect spring, and that the heat of compression when utilized can be made to return its full value of energy.

An air compressor in spite of its cooling apparatus usually furnishes compressed air at pressures following closely the adiabatic line, so that the illustration applies to a typical case so far as the compression is concerned. This subject of adiabatic compression has been fully referred to, and the difficulties which have stood in the way of isothermal compression have been pointed out in a pamphlet written by me about a year ago, entitled *Compressed Air Production*, published by the *Engineering News* Publishing Company, New York.

We have now seen that the heat of compression is not such a serious thing provided it can be utilized. The hot compressed air confined below the piston at the forty-five pound point, if transferred through pipes or otherwise to an air engine and maintained hot, will do as much work as we have just seen is possible when applied to the air compressor itself in driving the piston back to the starting point. To convey this air some distance hot, is a difficult matter, for compressed air though very slow in taking up heat, has so low a specific heat that it parts with its temperature rapidly. This loss of heat is the only serious obstacle, because, as we have seen, the friction loss in the pipe is not serious, and experiments have conclusively proved that leakage in a good system cuts no figure in the loss of

power. I have pointed out in *Compressed Air Production*, the reasons why clearance loss is of little consequence in an American air compressor. This is especially true in adiabatic compression because here what little clearance there is serves only to confine hot compressed air which acts as a spring, and which gives out a full return of power when the stroke is reversed.

As air parts with its heat rapidly, we cannot advise saving the heat during transmission by covering the pipe, so that we now suffer the loss of heat during transmission to go on, depending upon *restoring* the heat immediately at the air engine. Now this reheating is not, as some may suppose, a means by which the gain is only equal to the expenditure. Air is almost a perfect gas, and the application of heat is a direct transfer of energy to a substance which, through its elasticity, is capable of giving a full return. We burn a pound of coal under the boiler, and get only about ten per cent. back in power, because of the large loss in the stack, the loss in the exhaust, the difficulties in the way of utilizing the latent heat, etc., but when we heat compressed air, the thermal energy in the coal is stored in the air, and we are only limited in our efforts to utilize *all* of it by the reduction of pressure which takes place more rapidly than the reduction of temperature, and hence a warm exhaust. Radiation of heat between reheater and engine is also a source of some loss.

Returning to *Fig. 1*, let us imagine that the piston has been stopped at the forty-five pound point, and that this air, which, as we have seen, has a temperature of 320°, is transferred into a receiver and used at a point a mile away. The temperature will now be reduced to 60°, and if the system is well designed, we have nearly forty-five pounds pressure on the other end of the line, so that the volume of air will be reduced in size corresponding with the space underneath the lowest horizontal dotted line in the figure. This is marked "Volume 1." It is now used without reheating, to do work in an engine, and the line of reduction in pressure will now follow the lower dotted line marked "Adiabatic" until it reaches the point marked — 201°, which will represent

the temperature of the air when exhausted at atmospheric pressure. We now see that instead of getting back to the starting point the piston has only power enough to return about half-way.

If, on the other hand, heat were applied *during expansion*, the pressure would follow the line marked "Isothermal Expansion" and the piston would return to the starting point.

Another case is shown by the figure in which the air is compressed adiabatically to forty-five pounds, and heat enough is applied during expansion to maintain the temperature at 320°, until the air is exhausted at atmospheric pressure. This case illustrates the possibility of obtaining more power out of a given volume of air after compression than was expended at the compressor.

Reheating compressed air may be divided into two systems:

(1) That in which the reheating takes place in the conduit and before the air passes the valve of the engine.

(2) Reheating in the cylinder of the air engine after admission and cut-off.

The first case is the common practice, and is of value in that it saves *air volume*. It cannot increase the pressure because there is a continuous elastic air connection between the receiver at the compressor and the heater. Compressed air which leaves the receiver at a temperature of 300°, and which passes through a large conduit, losing its temperature, maintains its pressure because of this continuous elastic connection.

The reheater serves to reduce the *velocity* with which the air is drawn through the pipe, because it delivers hot air to the engine at the same pressure as though there were no reheater, and the temperature being higher, the power in each cubic foot of air remains the same though the *volume weight* is less. This valuable service performed by the reheater is limited only by the fact that air engines cannot work to advantage at temperatures over 350°; hence in a system that compresses air adiabatically to about sixty pounds pressure, and delivers it cold at a reheater, it is

possible to restore the temperature to the original point, and thus lose in power only through friction of the compressor, consumption of coal in reheater, friction in conduit, leakage, etc.

The second case is a problematical one, as thus far it has not been found practicable to reheat directly *in* the engine. The only device which seems to offer encouragement in this line is the system of internal reheating, which the writer has applied with some success, and which will be described later on. By internal reheating *directly against the piston of the air engine* an enormous advantage can be gained, and, as shown by *Fig. 1*, more power may be derived from a volume of compressed air than was originally expended at the compressor. This aditional power has been derived directly through heat acting upon the intrinsic energy which was stored in the free air before it entered the compressor.

The Paris reheater is simply a coke stove which surrounds the air pipe. It has been modified in various ways and at several places. The flue surrounds the air pipe nearly up to the steam chest of the engine, so that very little heat is lost. Radiation is also reduced to a small figure. Prof. Kennedy tells us: "The air was heated in passing through the stove up to 315° F. with a consumption of about 0·39 pounds of coke per I. H. P. per hour. As the admission temperature of the cold air was 83° only, this corresponds to an increase of about forty-two per cent. in the volume of the air and should, therefore (had the indicated efficiency remained the same), have been accompanied by a decrease of air consumption in the ratio of one divided by 1·42 or 0·70 inches. The air used in Paris is about eleven cubic feet of free air per minute per indicated horse-power. The ordinary practice in America with cold air is from fifteen to twenty-five cubic feet per minute per indicated horse-power. In Prof. Kennedy's experiments the engines were found to consume about fifteen cubic feet of air per minute per indicated horse-power without reheating.

The amount of fuel consumed during reheating is trifling. With the reheaters commonly employed it amounts to from one to two cents per horse-power per day. A more economi-

cal system of reheating will reduce these figures considerably. Prof. Kennedy says of the Paris reheaters: "It would not be difficult to design a more economical stove."

Fig. 2 illustrates a reheater in which the air is brought in contact with the fuel. The illustration is taken from a case which was put into actual service in connection with a rock drill. Immediately above the throttle valve and near the steam chest was placed an enlarged pipe fitting, in the interior of which, a little above the centre, was fixed a piece of wire gauze; above this gauze charcoal was thrown, some

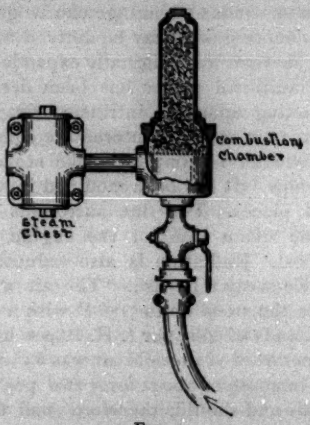


FIG. 2.

of it being in an incandescent state. The whole chamber was closed and the compressed air turned on. The air was thus brought in direct contact with the burning charcoal and was admitted to the drill cylinder extremely hot. With the consumption of a piece of charcoal an inch and a half in section and about two inches long, about two feet of hole were drilled. Instead of charcoal a substance called sestalit has been used with success, the advantage of sestalit being that it remains ignited for some length of time after the air has been shut off, and the products of combustion when discharged in a confined space are not objectionable.

The system of reheating by internal contact is theoretically the most perfect, because the full value of the heat units in the fuel are transferred to the air. The air pipe is at the same time the combustion chamber and the flue, the products of combustion adding about five per cent. to the volume of the air, in addition to the large increase through expansion by heat. Box is authority for the statement that "When oxygen and carbon combine, the volume of the carbonic acid gas formed is nearly the same as that of the oxygen consumed; when, therefore, a combustible contains carbon only, the volume of gas in the chimney is the same as

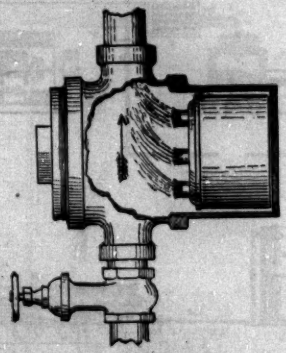


FIG. 3.

that of the air entering the fire, expanded of course to the volume due to the increased temperature, the oxygen consumed having been replaced by the same volume of carbonic acid gas. The nitrogen in the air is passive, passing through fire without chemical alteration. If the combustible contains water already formed and with which it is more or less saturated, vapor is formed from it and is added to the products of combustion."

A simple reheater is shown in *Fig. 3.*

A common lamp is placed within the air pipe, the oil being supplied to the lamp by means of a hand pump. I first applied this system to one of the pipe lines on the new

Croton Aqueduct, using a common miner's lamp placed in a four-inch pipe.

Fig. 4 illustrates an electric reheater. The air compressor is shown at *A*, compressed air being conveyed through pipe *B* to receiver *C*, thence through a conduit *D* to a pump *E*, situated (say) a mile away. In the engine room with the compressor is a dynamo *H*, which serves to light the mine. At a point near the pump a resistance coil *F* is placed in a chamber communicating directly with the compressed air. This resistance coil is made of any highly refractory substance, which resists the passage of a current to such an

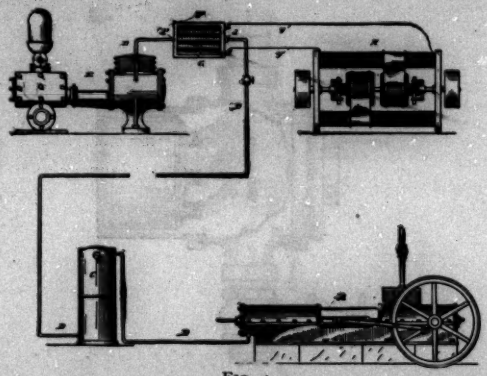


FIG. 4.

extent that the electricity is converted into heat, and the heat is thus imparted to the compressed air. Such a reheater as this has many advantages. The entire absence of combustion makes it perfectly safe for inflammable mines, and the ease with which it is applied by simply opening or closing a switch recommends it. It is also a cheap device and has been applied recently in the shape of a simple coil of wire placed in an air pipe. The conversion of electricity into heat is an economical one, it being a well-known fact that a current of any potential, when intercepted by sufficient resistance, may be entirely absorbed and returned as heat. This is accomplished unit for unit, and as

the loss in electric energy through transmission is low when compared with the shrinkage which takes place in compressed air, we here have a means by which the efficiency of the whole system may be increased by calling upon the electric wire to reheat the compressed air.

That it is theoretically possible to obtain from hot compressed air more power than was expended at the compressor, has been shown in *Fig. 1.* That this may not be confounded with perpetual motion but may be made clear, I have prepared a sketch, shown in *Fig. 5.*

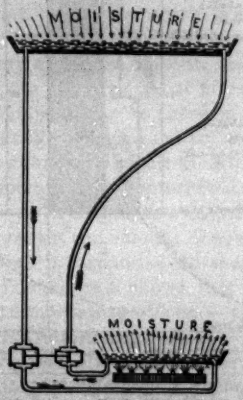


FIG. 5.

Sulphuric acid in its concentrated form, will when exposed in an open dish, absorb moisture from the atmosphere to the extent of about double its weight. A hypothetical assumption is made of a pump arranged to discharge sulphuric acid in the direction shown by the arrow to an open dish elevated (say) 100 feet. The amount of power necessary to discharge a certain quantity of sulphuric acid into this dish, is exactly equal to the power which the sulphuric acid is capable of giving out when falling back again, less the friction of the pump, leakage, etc. Now let us assume that the sulphuric acid in the open dish remained

there long enough to absorb moisture from the atmosphere until its weight has been doubled; it will thus obviously have twice the amount of power in falling back again, and if the friction and leakage losses were not too great it will be capable of driving the pump, and of returning an equivalent volume of the concentrated acid to the dish. If the same acid is used over again the moisture must be driven out, and lamps are shown in the sketch provided for this

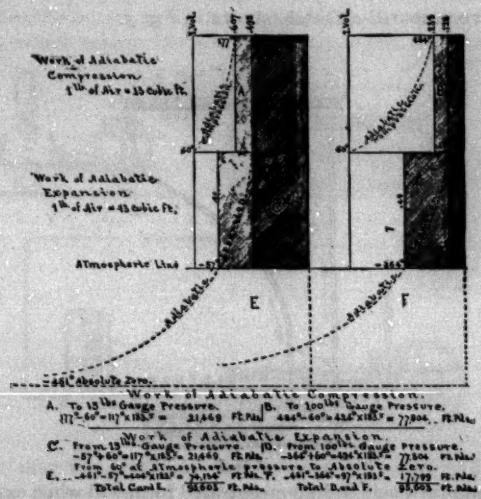


FIG. 6.

purpose. The analogy between this hypothetical case of sulphuric acid and one of compressed air is, that, as with acid we may draw power from moisture which is contained in the air, so with compressed air may we draw upon the intrinsic heat energy of the atmosphere.

These thoughts suggest the advisability of defining still further what is meant by intrinsic energy. Air being a practically perfect gas it will expand or contract in volume through a definite range in proportion to its temperature.

Experiments made with air at temperatures between the freezing and the boiling points of water, have given us the ratio of contraction of volume by reduction of temperature from which the absolute zero has been determined. The absolute zero of air is about — 461° F., and is that point at which any volume of air is reduced to nothing through expansion. In other words, the air may be said to be condensed at — 461°. We have therefore a base line which limits the power contained in any body of air.

Fig. 6 is a graphic diagram drawn for the purpose of illustrating the fact that the power which is contained in any body of air at a given pressure is dependent upon its distance in temperature above the absolute zero, and that there is as much power in a pound of air at fifteen pounds gauge pressure and 60° temperature, as there is in one pound of air at 100 pounds gauge pressure and 60° temperature. One pound, or thirteen cubic feet, of air at fifteen pounds pressure and 60° temperature, is represented by the space *C*. The available power in this air is 21,469 foot-pounds. By available power is meant the amount of power which can be utilized when this air is expanded adiabatically to atmospheric pressure. The diagram shows that when such pressure is reached the temperature will be — 57° F. There still remains in this air a certain amount of *intrinsic energy* and the diagram and figures show that this energy is equal to 74,134 foot-pounds. This added to the available energy gives us 95,603 foot-pounds, as the whole energy contained in one pound of air at fifteen pounds pressure and 60° temperature.

D represents one pound of air at 100 pounds pressure and 60° temperature. Its available energy is 77,804 foot-pounds, and its intrinsic energy is 17,799 foot-pounds or the total energy is 95,603 foot-pounds, which is exactly equal to the case just cited.

These figures prove the correctness of that thermodynamic law, which states that the power of any elastic gas is in direct proportion to its height of fall. So long as the temperature is above the absolute zero, there is as much power in the same body of air when expanded adiabatically from

a moderate temperature to an extremely low one, as when expanded from a high temperature to a moderate one, and this offers to some extent a limitation to that system of reheating which increases the volume without at the same time increasing the pressure.

Fig. 7 is a diagram which illustrates a typical case in American practice, where air is admitted to a compressor at 60° and compressed adiabatically to 100 pounds pressure. It is then transmitted a sufficient distance to cool it down to 60° temperature and expanded back to atmospheric pressure, the temperature falling to — 364°. The conditions

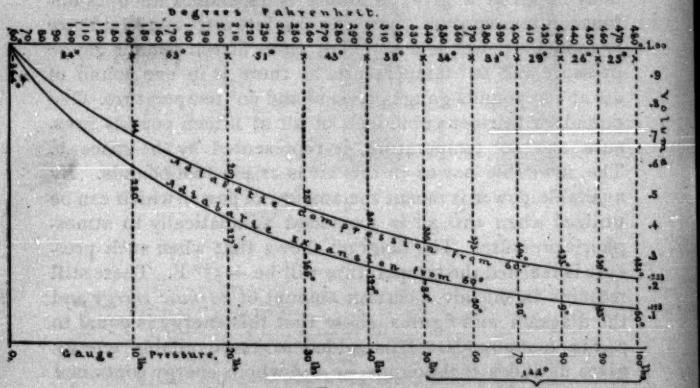


FIG. 7.

shown in the diagram are extreme and purely theoretical. In actual practice both compression and expansion are only approximately adiabatic.

Fig. 8 illustrates an economical condition of compressed air use in mines and tunnels. The power is generated electrically and is conveyed by wire to a point within a few hundred feet of the heading where a rock drill is at work. By means of an electric air compressor hot compressed air is produced adiabatically, and is expanded adiabatically in the cylinder of the drill, following closely the economical conditions illustrated and described in *Fig. 1*. Such a state

of things as this admits of an electric installation in the mine for the purpose of haulage, lighting, traction and pumping, to all of which uses electric energy has been successfully applied, and it gives us a means by which a compressed air drill may be successfully and economically operated at the heading. The air may be taken from the mine and when exhausted at the drill it serves to keep up a circulation in so confined a space as a heading, and as it is exhausted at atmospheric temperature there is no material change in the temperature of the mine. In some cases the air may be drawn through a flue from the outside, and thus through compression and expansion it will serve to ventilate the mine, as it does in the case of a compressed air installation. The economy of the system depends to its greatest

Combined Electric and Pneumatic System.
Showing Solenoid Air Compressor delivering hot air to Rock Drill
and thus giving a high efficiency.
The Compressed Air after Expansion is Exhausted at Normal Temperature.

FIG. 8.

extent upon the economy of electric production and transmission. Electrical engineers tell us that they can deliver electric energy several miles from the generating station with an efficiency of eighty per cent. If this is true its conversion into compressed air and its use as a power under the conditions shown in the illustration, may be accomplished at a very moderate reduction of efficiency, because as is plainly seen the losses commonly incurred in compressed air service do not here take place. Electric rock drills are subject to many costly limitations. Thus far they have not been successful, and it is a serious question whether or not it is possible to accomplish the drilling of rock by the percussive principle (which is the only true one), by an electric

engine which will be equal in weight, in price and efficiency to an air engine. The weight of a rock drill is one of its most conspicuous limitations, and from every basis of theory and practice a compressed air percussive engine will weigh less than half that of an electric one of the same power. An electric drill is made of copper which cannot compete in

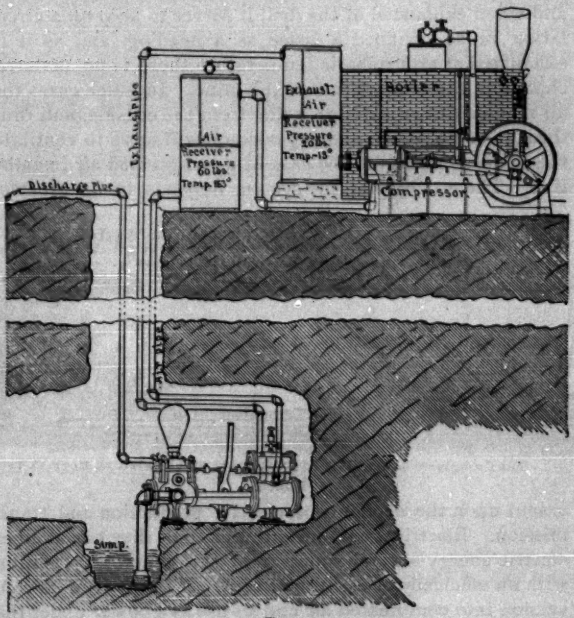


FIG. 9.

price with iron, and the durability of the apparatus is apparently in favor of the air drill. But as mines are likely to be lighted by electricity, and as there are many conditions of work favoring electric transmission for other purposes, we here have a means by which all the advantages of the air drill are maintained in an electric installation.

Fig. 9 illustrates what may be called an endless chain of

pneumatic power. An air compressor draws its supply of air from a receiver in which there is a pressure of twenty pounds. The air is compressed to sixty pounds, and is carried down a shaft and used to drive a pump. The exhaust of the pump is returned to the initial air receiver; and thus the same air is used over and over again, all of the exhaust pressure being utilized. As pumps usually exhaust at pressures from twenty to fifty pounds, a large saving is effected in this alone.

When starting, it is simply necessary to open a valve on the initial air receiver until a pressure of sixty pounds has been reached in the secondary receiver; the valve is now closed and the work goes on. The economy of this system is apparent. The heat of compression is converted into work in the pump, and a very low temperature of air is maintained. The economy of low initial temperature in air compression has been fully set forth in a diagram which I have published in *Compressed Air Production*, and a power diagram of such a system as this indicates several other economical points, notably the admission of compressed air instead of free air through the inlet valves, which serves to reduce the heat loss during compression and to equalize the resistance strains in the engine.

Fig. 10 illustrates in contracted form a complete pneumatic installation comprising boiler, air compressor, air receiver, air injector, supplementary air receiver, pipe for transmission, reheater and air engine. The reheater and air engine should be considered as situated from 1,000 feet to several miles from the compressor.

It will be observed that atmospheric air is drawn in the piston inlet tube of the compressor at 60° temperature. It is compressed adiabatically; that is, without any provision for cooling during compression, and in this way all of the power expended in the steam cylinder is converted into heat, which remains as power in the air. Perfect adiabatic compression, as previously stated, cannot be attained because of the absorption of heat by the metallic surfaces, radiation, etc. For the sake of illustration, however, the figures are given at adiabatic compression.

Now, we have seen that, if all of this heat can be utilized, it will return 100 per cent. in power, less such small items as friction, leakage, etc., and the purpose of this sketch is to call attention to a means by which at least a large part of this heat may be saved, and not wasted by radiation into the atmosphere or by absorption in water. An air injector is located between two air receivers, and the highly compressed or the highly heated air from the first receiver is admitted through the nozzle of this injector, and is thus converted into high velocity inducing free air from the atmosphere, and discharging an increased volume at a reduced pressure and temperature into a secondary

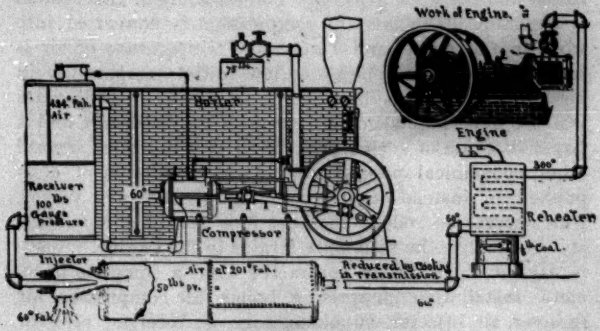


FIG. 10.

receiver. For the sake of illustration, the pressure in the first receiver is taken at 100 pounds and is reduced to fifty pounds.

This air injector has been tried with success though the experiments have not gone far enough to determine to what extent it will effect a saving in the production of pneumatic power. It has been found that with a pressure of eighty pounds in the first receiver, the injector will work discharging and inducing free air into a second receiver in which is maintained a pressure of sixty pounds. This difference of pressure may obviously be modified by the shape of the nozzle, sizes of pipes, etc., and it is probable that the

injector may be made to work at a difference between the two pressures of only ten pounds.

The principle is similar in many respects to that of the boiler feed injector about which there are so many mysteries. We know that not only is it possible to feed a boiler through an injector which takes the steam at a pressure lower than the boiler pressure, but the *exhaust injector* is a practical success. That we may exhaust steam from an engine and, by means of such exhaust, feed water to the boiler which supplies the engine with live steam, is indeed a mystery, and it is fair to assume that equally valuable and surprising results may be obtained from the induced air injector.

Mr. Green, the inventor of the Green system of ventilation, which is used on Trans-Atlantic steamers, is now conducting experiments looking toward the ventilation of the Forty-Second Street tunnel, New York, by means of air induced through an injector. His experiments have shown that one volume of air when passed through the nozzle of an injector at a pressure of five pounds, will induce thirty volumes of free air; that is, a volume efficiency of thirty to one. Mr. Green measured his air by means of a meter.

His conditions were similar to that outlined in the sketch, differing only in degree, and while it is not expected that so large a percentage of volume in free air may be induced, yet on the basis of figures alone, when compared with Mr. Green's experiments, we might expect from three to five volumes.

The velocity with which compressed air is discharged through a nozzle does not differ materially at pressure of fifteen pounds and over. The actual velocity with which compressed air at five atmospheres is discharged through a short pipe, is 658 feet per second, and at ten atmospheres the velocity is 649 feet per second. This is because high pressure air is more dense than air at low pressure, and just in proportion as the density increases does its resistance to movement increase. This is one of the limitations to the pneumatic dynamite gun. They started on about 500 pounds pressure and fell short of the mark. It appeared

that it was only necessary to increase the pressure to increase the range, but the limitations were soon discovered.

With air discharged through an injector nozzle at a velocity of 650 feet per second, it is easy to understand that free air will be induced and discharged with it into a secondary receiver. The nozzle should be constructed so as to offer the maximum amount of contact for the minimum volume of discharge, and such a nozzle has been built by Mr. Green; it takes hold of the induced air not only on the outside but also directly in the centre or core of the jet.

This is not a case where something is sought from nothing. The hot compressed air is converted into high velocity and thus the heat of compression is utilized. Were it not utilized in this way it would simply be discharged into the atmosphere by radiation, which is the usual practice in long-distance transmission in America.

Compressed air cannot be produced isothermally. In spite of the best system of injection combined with water jackets and a complicated apparatus, there will still be the heat of compression influencing pressure during compression. Compressors have been made which show cold discharge pipes and passages, and cold air in the receiver, but the largest part of this reduction in temperature has taken place *after* compression. If we cannot keep down the heat during compression, and if it be true that in keeping it down even to a reasonable extent, large complications are involved in the machinery, why not let it be produced and so simplify the apparatus, then let this *hot high pressure expanded air* be discharged through one or two injectors until its temperature has been reduced to a point *approximately what it will inevitably reach during transmission*, and thus *we have converted the heat of compression into air volume.*

The reheater shown in the sketch is little more than a common stove, the air pipes passing through the furnace. This saves *volume* of air only, it cannot increase the pressure. The engine which is driven by the compressed air should be provided with an automatic cut-off, and to insure economy it should exhaust at atmospheric pressure. It is obvious that when exhausting at atmospheric pressure

it will also exhaust at a comparatively high temperature, unless the air is first admitted at a pressure sufficiently high to admit of early cut-off and complete and economical expansion. This points to economy under some conditions by using high pressure air in an engine which works in connection with a system of reheating, and it also points to the highest economy which will be shown by that system which follows the conditions shown in the sketch, but which reheats or rather explodes the compressed air *behind the piston of the air engine after admission and cut-off.* This principle has been verified to some extent in certain oil and air engines, notably the Priestmann and Grigg, which have recently been brought to the attention of engineers.

CELLULOSE OR WOOD FIBRE.

By Prof. S. P. Sadtler.

[*A lecture delivered before the Franklin Institute, February 1, 1892.*]

The percentage composition of dry and ash-free cellulose corresponds to the formula $(C_6H_{10}O_5)_n$. It is, therefore, placed in the class of polysaccharides, to which starch and many of the gums belong. It must be understood, however, that this applies to the purified cellulose after the extraction from admixture with other associated principles. This extracting is done by exposing the moist vegetable tissue to the action of chlorine gas or of bromine water in the cold, and subsequent boiling in dilute ammonia, repeating this treatment until the alkaline solution no longer dissolves anything from the tissue or fibre. With many plants, such as cotton, flax, hemp, etc., this reaction, while requiring time and repeated action of the reagents, can be effected with thoroughness. With others such as jute, straw and compact wood the extraction is combined with greater difficulty, and when accomplished yields a product differing in important particulars. It is also often a very difficult matter to draw the line between *mixtures* and combinations

of cellulose with non-cellulose constituents of either fibres or tissues.

The following compound celluloses Cross & Bevan, who have made an especial study of this subject, consider sufficiently characterized to warrant special description under class names:

Pecto-celluloses.—Resolved by hydrolysis (with alkalies) into pectic acid and cellulose. Type—raw flax.

Ligno-celluloses.—Resolved by chlorination into chlorinated derivatives of aromatic compounds, soluble in alkalies and cellulose. Type—jute.

Adipo-celluloses.—Resolved by oxidation (with nitric acid) into derivatives similar to those from the oxidation of the fats and cellulose. Type—the cuticular tissue of leaves and fruit.

The pure cellulose obtained from cotton or linen fibre retains the microscopic features of the raw fibre and thus readily betrays its origin. It is insoluble in all simple solvents, but is first swelled and then dissolved by an ammoniacal solution of cupric hydrate. As pure cellulose is comparatively inert the reactions which would serve for its identification are few. One of them may be noted, viz: its reaction with iodine. This reaction differs from that of starch in requiring for its determination the presence of an auxiliary reagent of dehydrating power, such as sulphuric or phosphoric acid or zinc chloride. Such a solution containing iodine dissolved in potassium iodide admixed with zinc chloride, colors cellulose instantly a deep blue or violet.

Not much light on the constitution of the cellulose molecule is gained by studying the action of reagents upon it, but many very interesting and technically important derivatives have been obtained. One of the most interesting of these derivatives and of considerable technical importance is the oxycellulose, which is obtained by the action of weak oxidizing agents upon cellulose. That cotton fibre exposed too long to the influence of bleaching powder solution, or even repeatedly exposed to air and light, became weakened or "tendered," had been known for a long time before it was ascertained that this was due to the formation

of an oxycellulose, which differed in many of its properties from the original cellulose. The oxycellulose attracts the basic coloring matters from their solutions, and is dyed to full shade and fast color without previous mordanting. It also has a most remarkable attraction for vanadium compounds which it takes up from the most dilute solutions.

In many reactions, moreover, it bears much analogy to the lignin of the Ligno-celluloses.

Probably the most important of the derivatives of cellulose are the nitrates obtained by allowing strong nitric acid or a mixture of nitric and sulphuric acids to act upon cellulose. Taking the doubled formula $C_{12}H_{20}O_{10}$ for the cellulose, the highest nitro derivative formed is the hexanitrate $C_{12}H_{14}O_4(NO_3)_6$, the essential constituent of the true gun-cotton. This compound is insoluble in alcohol, ether or mixtures of both, as well as in methyl alcohol. Acetone alone dissolves it very slowly.

This most explosive variety of gun-cotton, according to Eder, is not produced by mixtures of nitre and sulphuric acid but only by using the strongest nitric and sulphuric acids, in which the cotton is immersed at a temperature not exceeding 10° C. (50° F.) for twenty-four hours. The pentanitrate $C_{12}H_{15}O_5(NO_3)_5$ is best prepared according to Eder's method by dissolving the hexanitrate or explosive gun-cotton in nitric acid at 80°–90° C. (176°–194° F.) and precipitating by concentrated sulphuric after cooling to 0° C. (32° F.). After washing the precipitate with water and then with alcohol it is dissolved in ether-alcohol and again precipitated with water. This nitrate, of which small amounts may be formed in the manufacture of explosive gun-cotton, is soluble in the mixture of ether-alcohol. The tetra and trinitrates $C_{12}H_{16}O_6(NO_3)_4$ and $C_{12}H_{17}O_7(NO_3)_3$ are generally formed together when cotton is nitrated with a more dilute nitric acid, at a higher temperature and for a much shorter time than that given for the hexanitrate. This mixture constitutes collodion pyroxyline and is soluble in ether-alcohol, acetic ether, acetic acid or methyl alcohol. The dinitrate $C_{12}H_{18}O_8(NO_3)_2$ always results as the final product of the action of the alkalies upon the higher nitrates,

and also from the action of hot, somewhat dilute nitric acid on cellulose. It is the lowest derivative attainable, a mono-nitrate having not as yet been formed.

The technical uses of these nitrated derivatives of cellulose are very important. An extremely interesting lecture was delivered in this hall a few weeks ago by Professor Munroe, of the Naval War College, of Newport, in which the characters of the explosive gun-cotton were discussed and its properties narrated. An equally interesting one might be made upon the now numerous applications of the lower nitrates, constituting as they do the bases of collodion or wet-plate photography, of the manufacture of celluloid and of pyroxyline varnishes. We will, however, pass on at present to note the chemical characters of the compound celluloses, the classification of which I have already given.

The first class, the pecto-celluloses, as the name indicates, are compounds yielding pectic acid when the cellulose is liberated from its combination. Thus, in the treatment of raw flax, the retting and bleaching processes are designed to break up this natural compound, the soluble pectic acid being washed away. Dilute alkalies effect the same result and this treatment is the one often employed in plant analysis to isolate the cellulose.

The third class, the adipo-celluloses, includes the cuticular tissue of fruits and of fibres such as cotton, straw, esparto, etc. Under the action of boiling nitric acid, these tissues are resolved into cellulose on the one hand and a series of fatty acids or products of their decomposition, suberic and adipic acids, such as are obtained from cork tissue, whence the name adipo-celluloses for the class.

In the second class, the ligno-celluloses, we have included by far the most important and interesting of the compound celluloses, viz: the different forms of woody tissue and lignified fibres, such as jute. The last-mentioned fibre indeed shows so clearly the nature of the combination between cellulose and what is termed lignin, that a study of it has thrown much light upon the characters of the whole class, and has aided chemists in getting a clear understanding of the methods for isolating cellulose from its combination in

the compact woods, which are now so largely used as a source of paper-making material.

Jute is a compound of twenty-five per cent. non-cellulose or lignin and seventy-five per cent. cellulose. The non-cellulose constituent is more readily attacked by reagents than the cellulose. Thus if the compound fibre be first boiled with a weak solution of an alkaline hydrate and then exposed to moist chlorine, the non-cellulose is attacked and on subsequent boiling with sodium sulphite solution the decomposition into cellulose and soluble non-cellulose derivatives is complete. Dilute nitric acid also attacks the non-cellulose, resolving it into soluble products and can be used to isolate the cellulose, but it attacks the latter somewhat also.

Wood consists of about two parts of cellulose in admixture with one part of lignin. Very characteristic color reactions are obtained by moistening any of these lignin-containing compounds with phenols, such as phloroglucin, and hydrochloric acid. They are also colored carmine by an alcoholic solution of pyrrol and deep yellow by solution of aniline sulphate. They take up organic dye-colors very much like the oxycellulose before referred to. Among the decomposition products of the lignin or non-cellulose have been found vanillin, coniferin and several wood-gums allied to gum arabic. Indeed a recent writer places lignin, because of its composition, amongst the class of gum resins. He has found in the products of the sulphite process for preparing wood-pulp as well as in those of the soda process, transparent resinous substances which are very similar in reaction to the arabic acid of natural gum arabic. He therefore is led to offer the following theory of these two well-known chemical wood-pulp processes. If wood is boiled under great pressures with caustic soda the lignin is decomposed. The gummy matters, resins and phenols, are dissolved and the volatile compounds, *e.g.*, terpenes, etc., escape. Cinnamic aldehyde and vanillin polymerize and coniferin is decomposed. It is well-known that sulphurous acid has a decomposing or polymerizing effect upon many groups of organic compounds. In the sulphite process, it

first decomposes lignin and then the free arabic acids decompose the sulphite of lime, hereby forming the calcium salt of the arabic acid which remains in the solution while the free sulphurous acid escapes. The author is of opinion that the sulphite process is in the main hereby explained. The terpenes and aldehydes mostly polymerise and escape, together with the other volatile aromatic compounds of the woody matter as well as the sulphurous acid, whilst the non-volatile substances, *e.g.*, the resins, are left, parts of which remain as the calcium salts of the resin acids."

The technical applications of this class, as said before, are already of enormous importance. The increasing use of wood-pulp as a paper-making material is the explanation of this. We will now take up for brief notice this most important of the cellulose industries. Wood, as before stated, contains cellulose in combination with lignin, together with mineral salts and some little coloring resin. The proportion of these constituents varies somewhat in different varieties of wood, as shown in the accompanying table from Müller.

	Birch.	Beech.	Lime.	Pine.	Poplar.
Cellulose, ...	55·52	45·47	53·09	56·99	62·77
Resin, ...	1·14	0·41	3·93	0·97	1·37
Aqueous extract, ...	2·65	2·41	3·56	1·26	2·88
Water, ...	12·48	12·57	10·10	13·87	12·10
Lignin, ...	28·21	39·14	29·32	26·91	20·88

The practical problem now is to extract the cellulose in such condition as to enable it to answer the requirements of the paper-maker, viz: strength and length of fibre, which give it felting power, and for finer papers freedom from resinous and coloring impurities, such as would prevent its use as a mixing ingredient or substitute for linen cellulose.

We divide the wood-pulp methods into the two great classes of mechanical and chemical.

In the mechanical wood-pulp process, the wood, cut into blocks, is pressed against revolving grindstones, the surface of which has been roughened by the cutting of grooves.

The wood is placed so that the revolving stone shreds or tears the fibres laterally and not transversely to the line of the fibre, while a stream of water kept flowing over the stone, washes off the fibre as rapidly as it is loosened. Even then the fibres are relatively short as compared with those obtained by the chemical processes. The pressure of the blocks of wood against the stones is maintained either by screws capable of adjustment as required, or by hydraulic pressure. The pulp as washed off the stones is passed over screens, which retain larger fragments to be ground again and allow the finer pulp to pass through and this is then farther sorted by sieving.

The quality of the mechanical pulp is improved by steaming the wood thoroughly before shredding, so that the wood being softened a longer fibre may be torn off. Such mechanical wood-pulp is made and comes into commerce under the name of "steamed pulp." The specimens shown are from the Androscoggin Pulp Company, of Brunswick, Me., and are mixed spruce and pine. The steaming of the wood is continued for eight to ten hours at a pressure of about forty pounds, and drip valves are attached to the upright boilers used, so that the wood is not soaked in hot water but exposed to the action of steam only.

Paper made from mechanical wood-pulp is very liable to become discolored by the action of air and light, the lignocelluloses being much more readily acted upon than the celluloses isolated from them. This fibre is, moreover, of very slight felting power on account of its shortness, but it is cheap and is used in large amounts for filling material, or it may be exclusively for cheap newspapers.

In the preparation of chemical wood-pulp, on the other hand, the lignin or non-cellulose constituents of the wood are decomposed and eliminated, so that a relatively pure cellulose remains, in amount varying with the process employed and the kind of wood taken. The processes that have been found applicable for this decomposition of lignin and separation of cellulose are classified as follows by Cross & Bevan, in their *Paper-making:*

VIEW OF THE CHEMICAL PROCESSES FOR DISINTEGRATING WOOD.

(1) *Aqueous alkalies.*—Hydrolysis aided by alkali directly, also indirectly by combination with products of resolution. (Watt and Burgess, 1853; Houghton, 1857.)

(2) *Solutions of alkaline sulphides.*—Hydrolysis, aided by alkaline bases directly and indirectly by combination with the products. Reversal of hydrolysis lessened by presence of reducing agent. (Jullion, 1855; Blitz, 1883; Dahl, 1884.)

(3) *Water.*—Hydrolysis, aided by acids formed from the wood. Limit of action determined by reversal of hydrolysis, *i. e.*, dehydration aided by oxidation. (Fry, 1867.)

(4) *Water, together with neutral sulphites.*—Simple hydrolysis. Products removed from sphere of action by combination with base and sulphite. Oxidation prevented by presence of sulphite. (Cross, 1880.)

(5) *Aqueous acids.*—*a.* Oxidizing and hydrolytic. Nitric acid. (Coupier and Mellier, 1852; Barre and Blendel, 1861.) Nitro-hydrochloric. (Orioli, 1865.)

b. Simply hydrolytic. Hydrochloric acid. (Bachet and Machard, 1864.)

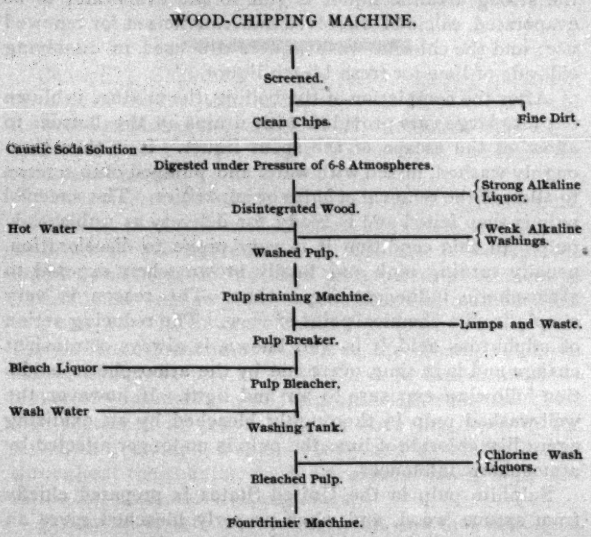
c. Reducing and hydrolytic. Sulphurous acid. (Tilghman, 1866; Pictet, 1882.)

(6) *Bisulphites.*—Hydrolysis aided primarily by sulphurous acid and secondarily by combination of products with bisulphites, also by prevention of oxidation. (Tilghman, 1866; Mitscherlich, 1874; Ekman, 1881; Franke, 1881; Graham, 1882.)

The processes in practical operation at the present time have narrowed down to those under two of these headings, viz: soda pulp processes and "sulphite," or more correctly bisulphite pulp processes.

The first of the soda processes was that of Watt & Burgess, and this, with some modifications, is still in successful use to-day. It depends, as was mentioned before, upon the fact that the lignin is decomposed by the caustic alkalies under pressure, and the products of the decomposition go into solution. Its drawbacks are that under the conditions needed to complete the disintegration of the wood, the cellulose portion itself is attacked, and hence, the yield of finished pulp is smaller than by some other processes. And when the regeneration of the soda was incompletely carried out, as was often the case, the process was an expensive one. Great improvements have been effected in this matter, however, and with the present high percentage

of recovery, the process makes a better showing. A diagram, showing in graphic form the several stages of the Burgess soda process as carried out in this city, is shown.



Of the sulphite processes mentioned in the diagram already given, that which is most generally employed in this country is the Mitscherlich, while in England the processes of Ekman and Franke, as modified by Partington, have been tried in addition. The Mitscherlich and the Franke processes use bisulphite of lime, while the Ekman process takes a bisulphite of magnesia. The sulphurous oxide, of course, is produced by the burning of sulphur or pyrites, and this gas, after being cooled, is passed into milk of lime, placed in large tanks, which are used either singly or connected in series for more complete absorption. This bisulphite liquor then acts upon the chips in closed boilers or "digesters" under a pressure of ninety pounds, for some

nine to ten hours. A longer boiling at somewhat lower pressure is also used in some cases.

Of the side-products, shown to the right in the diagram, the strong alkaline liquor is run to the evaporator to be evaporated, calcined, dissolved and causticized for renewed use; and the chlorine wash liquors are used in dissolving chloride of lime for fresh bleach liquor.

After the completion of the boiling, the mixture is blown out into large vats provided with drains in the bottom to allow of the escape of the spent liquor. It is then thoroughly washed, mixed with water and pumped onto screens to allow of the removal of chips or impurities. The screened pulp is then felted and is ready for delivery as unbleached pulp. In this condition it is very prone to discoloration, usually turning pink and finally brown when exposed to atmospheric influences for a time. The reason is very simple from a chemical point of view. The reducing action of sulphurous acid, it is well known, is always a transient change and is in time overcome by the atmospheric oxidation following exposure to air and light. If, however, the well-washed pulp is thoroughly bleached by an oxidizing agent like chloride of lime, the pulp is no longer affected by atmospheric influences.

Sulphite pulp in the United States is prepared chiefly from spruce wood, and when properly bleached gives an almost pure cellulose, white and of strong fibre.

The wood-pulp production of the United States more than trebled during the decade between 1880 and 1890, and now employs between 200 and 300 factories, of which the larger number run, of course, on mechanical wood-pulp, although the chemical wood-pulp processes are gaining ground relatively faster, and are at present coming into greater favor.

OBITUARY.

CHARLES J. SHAIN.

Charles J. Shain, for nearly half a century an active member of the Institute, and for several years a member of its Board of Managers, recently died at Atlantic City, N. J., where, for some time previous to his death, he had made his permanent home.

The subject of this sketch was born in Philadelphia, October 27, 1822. He was educated at private schools, and as a minor was apprenticed to William J. Young, the founder and head of the then principal establishment in Philadelphia engaged in the manufacture of mathematical instruments. In 1850, he formed a co-partnership with Joseph Knox (one time foreman in the Young establishment), under the firm name of Knox & Shain, manufacturers of engineering and telegraphic instruments. This firm continued in active business until the death of Mr. Knox, in 1877, and became widely and favorably known throughout the country, their instruments taking high rank in the estimation of civil engineers.

It may be of interest to record the fact that the instruments used by the late Edgar Thompson, in the first survey of the Pennsylvania Railroad, were those of Knox & Shain.

Upon the severance of this long-time connection, by the death of his associate, Mr. Shain retired to private life. His connection with the Franklin Institute dates from his election to membership, in the year 1843, and was continued uninterruptedly to the time of his death. He was elected to the Board of Managers in 1884, and served until 1887, when, on account of his removal from the city, he declined a re-election. He was warmly interested in the Institute, and contributed freely of his time and special knowledge to the furtherance of its work. He died at Atlantic City, on November 23, 1891, of Bright's disease, in his 70th year.

His unvarying courtesy and amiability greatly endeared him to his fellow-members and officers, by whom his loss is sincerely deplored.

Mr. Shain leaves a widow and two sons to survive him: Dr. Francis W. Shain, for some years surgeon in the service of the Red Star Line and at present a practising physician in Jersey City, and Chas. D. Shain, district manager for the Edison Company, of New York. W. H. W.

EUGENE H. COWLES.

Eugene H. Cowles, who died at El Paso, Tex., on April 21, 1892, at the early age of thirty-eight, had attained a world-wide recognition by the scientific world for his inventions in connection with the manufacture of aluminum. These inventions, in the origination and development of which he was assisted by his brother, Albert H. Cowles, involved in principle the application of the heating action of the electric current for the reduction of aluminum and other metals, and are too well known to need extended reference in this place. It will suffice to allude to the fact that the result of the Cowles inventions was a revolution in the aluminum industry as profound as that caused by the earlier work of Deville. The process enabled the inventors to produce the alloys of aluminum vastly more cheaply than had hitherto been possible, and at once a large demand for these products was created. To carry out their process effectively, the Messrs. Cowles were compelled to do a large amount of pioneer work, in connection with the design of dynamos of large power, the control of currents of hitherto unprecedented magnitude, the manufacture of carbon electrodes of great size, and to work out, in the face of many difficulties and discouragements, many details of operation that now seem comparatively easy, but for which at that time there were no precedents to build upon. For all this pioneer work and for the successful introduction of their process in this country and in Europe, the brothers Cowles deserve the highest praise.

The first institution of learning to take note of, and to recognize the importance of the inventions of the Cowles brothers, was the Franklin Institute. Shortly after the first public announcement of the Cowles process, an invitation was extended to the inventors to read a paper on the subject before the Institute, which was accepted by the subject of this sketch. This paper was presented at the stated meeting held January 20, 1886, and, under the title, "The Production of Aluminum and its Alloys in the Electric Furnace," appears in the impression of the *Journal* for February, 1886. It was an able and comprehensive treatment of the subject, and reflects the highest credit on its author.

The success with which the efforts of the inventors to secure the general adoption of their process was crowned, sufficiently demonstrates that their faith in its commercial and technical value was neither misplaced nor exaggerated.

The Franklin Institute, in recognition of the merits of the invention of the Cowles brothers, awarded to them, in 1886, the highest honor in its gift—the Elliott Cresson Medal—"for their invention of a new process in the metallurgical arts for the reduction of refractory substances," and recommended the award of the John Scott Legacy Medal and Premium to the inventors, "for their electric smelting furnace," which recommendation was subsequently confirmed by the Board of Directors of City Trusts.

Subsequent events demonstrated that the judgment of the Institute in estimating the value of these inventions so highly was fully justified. The late Mr. Cowles never forgot the early appreciation of his work by the Institute, and cherished the tokens of its recognition with affectionate regard.

His untimely death before he had yet reached the measure of years when those better equipped with physical endowments are in the prime of their powers for usefulness, is a loss which all friends of science will learn with sincere regret. W. H. W.

PROCEEDINGS

OF THE

CHEMICAL SECTION

OF THE

FRANKLIN INSTITUTE.

[*Stated meeting held Tuesday, April 19, 1892.*]

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, April 19, 1892.

Dr. Wm. H. Wahl, President, in the chair.

Professor Henry Trimble read a paper on "Chestnut-bark Tannin." This paper gives the results of an investigation which forms the second and final part of a research to determine whether any differences exist between the tannin extracted from the wood of the tree on the one hand and the bark on the other. The results of the investigation of the tannin from the wood have already been published by Prof. Trimble in a former paper read before the Section. The results formed a subject of a brief discussion, and the paper was submitted for publication in the *Journal*.

A sample of the tannin was exhibited by the author.

A brief communication from Mr. Chas. E. Ronaldson, M.E., on "The Influence of Bottles upon Wines," was read and discussed by the Section. The same related principally to the progress made in the United States by glass manufacturers in producing glass of proper composition for the purpose named.

The Section then adjourned.

WM. C. DAY, *Secretary*.

CHESTNUT-BARK TANNIN.

By Henry Trimble.

[*Read at stated meeting of the Section, held Tuesday, April 19, 1892.*]

In the manufacture of chestnut extract the bark and wood are used together, the latter naturally exceeding the former in amount, as well as in yield of extract.

It has been thought desirable to determine if there exists any differences in the character of the tannins from these two parts of the tree, and the results of an investigation of that from the wood were published in this *Journal*, **132**, p. 303.

The material in this case was obtained from a tree thirty years old, cut in August; the bark was immediately removed, air dried and powdered.

The total tannin was found to be 7·31 per cent. The wood yielded 7·85 per cent. The other important constituents in the bark were found to be in per cent., 1·09 of resin, 3·06 of mucilage, 1·35 of glucose, 10·00 of moisture, 4·71 of ash and 45·44 of cellulose.

The tannin, as extracted by commercial ether, was much darker in color than that similarly prepared from the wood, but an equally light-colored product was obtained by first precipitating in fractions with lead acetate, and then further treating the middle and most abundant one with salt and acetic ether. The aqueous solution of this portion, after removal of lead by hydrogen sulphide, when saturated with common salt, separated a dark-colored portion which rose to the top, and was easily removed in one mass after standing twenty-four hours. The remaining light-colored solution was agitated with acetic ether, the latter separated, and, after removal of the solvent under reduced pressure, a light-colored product was obtained. This was then dissolved in water, filtered and the solvent distilled off under reduced pressure; it was then dissolved in ether, filtered and again dried in a vacuum at the temperature of a boiling water-bath.

The product was a light, almost white, porous mass of a reddish-brown shade, which was completely and readily soluble in water and the other usual solvents, and in all other respects corresponded with the chestnut-wood tannin described in the previous paper, as well as with gallotannic acid. It did not give any reaction for glucose, from which compound it was rather more easily purified than the product from the wood.

The average of two closely-agreeing combustions gave the following percentages, with which are given those from the tannin of the wood, for comparison:

	Chestnut-bark Tannin.	*Chestnut-wood Tannin.*
C,	52·42	52·11
H,	4·67	4·40
O,	42·91	43·49
	100·00	100·00

The conclusions to be drawn from this work are that the tannins from chestnut bark and wood are identical, and, although ultimate analyses show high percentages of hydrogen in both, they are believed to be identical with gallotannic acid.

In an investigation of the darker tannin precipitated from aqueous solution by salt, the following percentages were obtained:

C,	55·18
H,	4·72
O,	40·10
	100·00

This product was considered to be a mixture of the tannin with its anhydride.

PROCEEDINGS

OF THE

ELECTRICAL SECTION

OF THE

FRANKLIN INSTITUTE.

[*Stated meeting, held Tuesday, April 5, 1892.*]

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, April 5, 1892.

Prof. Edwin J. Houston, President, in the chair.

Present, twenty members and visitors.

The minutes of the previous meeting were read and approved.

The Treasurer reported the balance in the treasury, and presented bills for lantern slides, printing, etc., which were approved and ordered paid. The Secretary announced the death of Mr. Thomas Hockley, active member, on March 12, 1892, and upon motion the chairman appointed a committee to draft suitable resolutions for the section.

Mr. C. H. Bedell read a paper on "Dynamo and Motor Calculation," with illustrations. Referred for publication.

Mr. Herbert S. Lloyd (visitor) described, with the aid of a working model, a new method of wiring incandescent lights, so that they could be controlled by switches from any number of points, on two or three-wire systems.

Prof. Houston read a letter from Prof. Elihu Thomson, in which the latter described some interesting experiments he had been making with alternating currents of high potential. It was also stated that Prof. Thomson would probably show these and other new experiments before the Section at a future meeting.

There was an informal discussion on the trolley system of electric street car propulsion, and on the conditions under which the passage of an electric current through the body would probably be fatal to life.

Prof. Rondinella proposed to amend Sec. 1 of Art. II of the By-Laws, by striking out the word "first" and inserting in its place the word "fourth," making the section read, "The Stated meetings of the Section shall be held on the fourth Tuesday of each month at 8 P. M., except during the months of July and August." (This amendment will come up for action at the next stated meeting.)

The meeting then adjourned.

L. F. RONDINELLA. *Secretary.*

CORRESPONDENCE.

To the Committee on Publications, Franklin Institute, Philadelphia.

GENTLEMEN:—Will you kindly publish in your *Journal* a few remarks upon the article by C. B. Dudley, Ph.D., on pp. 81 and 93 of the *Journal*, current volume?

As a member of the firm of Torrey & Eaton, New York, I have given much attention to the analysis of bearing metals, having personally manufactured 1,000 tons of various alloys, and have carefully read the article by Dr. Dudley. Knowing his experience as an analyst and of his high standing as a member of the Mechanical Engineers, I was surprised to note that among the various analyses of bearing metals given, he has made several grave errors in the analysis of magnolia metal. This may work to the injury of a company which has done much to advance the interests of mechanics.

I am looking at this matter from an entirely scientific standpoint, and would not expect the *Journal* to take it up in any other way.

In the analysis of magnolia metal, Dr. Dudley has overstated one constituent part and has omitted tin (which it always contains) and other material. On the same page is given an analysis of antimonial lead, which may be correct, but not an ounce of this is ever used in magnolia metal, and the public will compare it with the magnolia analysis as given. This may work to the injury of the reputation of the makers of magnolia.

Respectfully yours, H. G. TORREY.

BOOKS RECEIVED.

[In sending books for notice in the *Journal*, publishers are requested, for the information of the reader, as well as for their own advantage, to give the price. This announcement by title will be followed, in most cases, by a review, which will appear at the earliest opportunity.]

Brainard, F. R. *The Sexant.* New York: D. Van Nostrand Company. 1891. 24mo. Price, 50 cents.

Burke, M. D. *Brick for Street Pavements.* Cincinnati: Robert Clarke & Co. 1892. 8vo. Paper. Price, $1.

Church, I. P. *Notes and Examples in Mechanics.* New York: John Wiley & Sons. 1892. 8vo. Price, $2.

Duquesnay. *Résistance des Matériaux.* Paris: Gauthier-Villars. 1892. 16mo. Price, 3 francs.

Dwelshauvers-Dery. *Étude Experimentale Calorimetrique de la Machine à Vapeur.* Paris: Gauthier-Villars. 1892. 16mo. Price, 3 francs.

Gouilly, Al. *Transmission de la Force Motrice par Air Comprimé ou Raréfié.* Paris: Gauthier-Villars. 1892. 16mo. Price, 2 francs.

Merriman, M. *Text-Book on Retaining Walls and Masonry Dams.* New York: John Wiley & Sons. 1892. 8vo. Price, $2.

Ohm, G. S. *The Galvanic Circuit Investigated Mathematically.* New York: D. Van Nostrand Company. 1891. 24mo. Price, 50 cents.

Picon, R. V. *La Distribution de l'Électricité.* Paris: Gaulthier-Villars. 1892. 16mo. Price, 2 francs.

Plympton, G. W. *How to Become an Engineer.* New York: D. Van Nostrand Company. 1891. 24mo. Price, 50 cents.

Richard, Gustave. *Les Nouveaux Moteurs à Gaz et à Pétrole.* Paris: Uve. Ch. Dunod. 1892. 4 vols. 8vo. Price, 75 francs.

Staley, C. and G. S. Pierson. *The Separate System of Sewerage.* New York: D. Van Nostrand Company. 1891.

Tillman, S. E. *Elementary Lessons in Heat.* New York: John Wiley & Sons. 1892. 8vo. Price, $1.50.

BOOK NOTICES.

A Manual of the Steam Engine. Part II. Design, Construction and Operation. By Robert H. Thurston, A.M., LL.D., Dr. Engineering. New York: John Wiley & Sons. 1891. Pp. xxiv, 934.

This second portion of this latest of Prof. Thurston's works is fully up to the standard of the first volume, and perhaps, from the full and able review of that portion in the *Journal*, little more need be said. The work is divided into chapters on design of the steam engine; design of valve gearing and steam distribution; regulation of the engine, governors, fly wheels and inertia effects; construction and erection; operation, care and management of engines; engine and boiler trials; specifications and contracts, and finance.

It is the last chapter that will be of most interest to engineers generally, as the author has here brought together a large amount of data not heretofore collated, and which will be interesting reading to every engineer. The blank forms used for determining costs, published by Mr. Towne in the *Transactions* of the American Society of Mechanical Engineers, are here reproduced together with the forms printed in the *Transactions* of the National Electric Light Associations.

Numerous instances of large savings from modifications of steam plants are given. Estimates are given as to the costs of large steam plants and of boilers, but it is not possible from the text to tell just what is included in the estimate. Tables follow giving the number of attendants required on vessels of different nationalities. Costs of engines and boilers under different conditions are given, which are valuable if one has the original papers at hand to determine the conditions under which the estimates are made. For instance, taking an engine from one of the tables we have a stationary non-compound engine of 56·8 I. H. P., cost $5,331 (of course meaning plant, but

not saying so), using twenty-seven pounds water per I. H. P. and 3·27 pounds coal. This is rather an odd combination of figures, but may have been right when first printed in 1883.

This is followed by some costs of construction, taking the case of a passenger locomotive, and by the divisions of the labor costs among the different departments of a manufacturing establishment. The cost of repairs is then taken up and an example given.

The costs of operation are given for a few cases, noting the difficulty generally found in getting these costs exactly. Examples are given showing the cost of small engines using gas, steam and hot air. The relation of cost values and durability, and the arithmetical rules for computing interest are explained. The questions of the efficiency of the steam boiler from the designer's and from the owner's standpoint are stated.

The next point treated of is that of lubrication, and considerable data as to the amount of oil that has been used under different conditions have been collected. The author deduces an arithmetical solution of the treatment of this portion of the subject of costs. A table gives the cost of simple and of compound engines of from 250 to 700 horse-power and tables showing the daily and yearly running expenses of engines of various kinds and under various conditions.

A rather interesting thing is the plan of a steam plant in connection with which the author says: "The 'steam plant,' so-called, thus consists of the whole arrangement of engines, boilers, and all accessories, and its design frequently involves many important questions arising from the conditions of location, and of costs at the chosen locality. In the figure, these have been studied with a view to securing the best and most convenient location of parts, actually and relatively, etc. The plant referred to consists of two return tubular boilers and two engines driving four dynamos.

The subject of electrical energy is taken up and considerable space given to the conditions under which it is used and to the data relating thereto. The last article is devoted to the transmission of power and here again considerable valuable data have been collected.

While Prof. Thurston on the title page states that the work is intended for engineers and technical schools, it can be read with profit by any one interested in steam engines, as the mathematical parts are not at all essential to a fairly complete mastery of its contents, although there are some portions, as for instance those relating to inertia effects, which are rather beyond the comprehension of one not well versed in mathematics. H. W. S.

The Zodiacal Light. By M. A. Veeder, M. D. Extracted from *Proceedings of the Rochester Academy of Science.* Vol. i.

This is one of the many attempts made to explain the mysterious phenomenon known as the Zodiacal Light. The author attributes the phenomenon to light reflected from an extension of the solar corona, consisting of meteoric particles. The paper is attractively written and the explanations are at first sight plausible, but upon closer examination they fail to impart conviction to

the reader. While the increased brightness observed during spring and autumn may be satisfactorily explained, it is not at all clear why the light should be brightest on the evenings of spring and the mornings of fall, since the spectator has practically the same standpoint on both mornings and evenings. Nor is there any reason why the phenomenon, as explained, should be seen most pronounced in the tropics. A difference of the point of observation of several thousand miles to the north or south of the equator, is so trifling that the observed diminution of the brightness of the light as the distance of the equator is increased, cannot be accounted for. In order to still further confirm the existence of meteoric matter, the author suggests that these meteors take part in conveying those electric impulses from the sun to the earth, which, according to our experience, are transmitted during periods of solar eruptions. This assertion is also open to objections. These electric disturbances, being transmitted from the sun to the earth by induction and not by conduction, a transmitting medium is not required. H. B.

ANNUAL REPORT OF THE DIRECTOR OF THE DRAWING SCHOOL OF THE FRANKLIN INSTITUTE FOR THE SESSIONS 1891–92.

The attendance during these sessions has been greater than ever before, with the single exception of last year, again necessitating the division of the classes into two sets to attend on different evenings because of want of room in this very inadequate building. This department of the Institute is as poorly provided as the others with facilities and suitable appliances and surroundings for the proper prosecution of its useful and valuable work. It has led for years in the system and methods of teaching mechanical drawing, and is gradually reforming the science throughout the country, and yet has been compelled to do this at a minimum of expense and in unsuitable quarters.

The benefit of a systematic and progressive course has been well demonstrated by the work of the Senior Classes this year, which is of a higher average than ever before. This work is of too technical and scientific a nature to make a popular or attractive display, but the benefit to the student of receiving a thorough course of instruction, which will be important to his future, is far greater than if the time was spent in elaborately executing, coloring and shading a few show-pieces. The time of a night school is too limited to attempt results which would greatly impress the laity, and is much better spent in teaching principles and methods and in laying a solid foundation for the future.

The corps of instructors, comprising Messrs. Clement Remington, Lucien E. Picolet, George W. Irons, George S. Cullen, H. Allen Higgins and William H. Sheahan, possesses the great advantage that its members combine a thorough theoretical knowledge of their several branches with the practical application of them in actual work, and this circumstance has much to do with the great amount of benefit, which the intelligent pupils derive during their limited attendance at this night school.

The following pupils are entitled to Honorable Mention:

In the Junior Classes.

Arthur Bentley,
G. W. Hassellund,
James H. Leicht,
Henry J. Nelson,
A. F. Abronski,
William F. Troost,
Milton B. Stout,
T. F. Kelly.

In the Intermediate Classes.

Malcolm Lovett,
Howard R. Lamborn,
Austin Riegner,
James Marshall,
Samuel G. Barnard,
Bert. Bilhartz,
Eric Ostram,
N. Battle,
A. Martin Devoe,
Christian Hagenlocher.

In the Senior Classes.

Walter Hensel,
William Saile,
Bruce Ford,
Charles Rowe,
Abraham P. Weckerley,
William H. Simmons,
Joseph Royal,
William T. Westbrook, Jr.

In the Architectural Class.

George W. Raynor,
Charles P. Jarden,
Lewis C. Butler,
George H. Robinson,
Thomas Noble.

In the Free-Hand Class.

Robert F. Scheicher,
George T. Blaisse, Jr.,
Max L. Kohl,
Walter L. Allen,
Godfrey Semper.

The following pupils are awarded scholarships from the B. H. Bartol Fund, entitling them to tickets for the next term, beginning September 20, 1892:

Walter Hensel,
William Saile,
George W. Raynor,
Malcolm Lovett,
Bert. Bilhartz,
Arthur Bentley,
A. F. Abronski,
William F. Troost.

The following pupils, having attended four terms and completed satisfactorily a full course, are awarded certificates:

Henry Aichele,
Edward C. Aitken,
Walter L. Allen,
Franklin W. Biedert,
George T. Blaisse, Jr.,
Julius Block,
Frederick Buehler,
Clifford I. Hewitt,
Joseph M. Hewlett,
George Lutner,
Alva S. Mackenzie,
Charles McLoughry,
John Rigling,
Charles Rowe,

Charles F. Cochrane,
George T. Coleman,
William S. Cooper,
Frank J. Crowne,
Lorenzo C. Dilks,
Jackson Dunlap, Jr.,
Henry B. Etter,
Herman Hammer,
Walter Hensel,
Andrew Sauer,
Godfrey Semper,
William H. Simmons,
George W. Todd,
Richard H. Trimble.
Paul G. Webb,
Allen Wilson,
Thomas M. Worn.

The next term will begin September 20, 1892, when endeavor will be made to maintain the progressive spirit of this department of the Institute.

WILLIAM H. THORNE, *Director*.

Franklin Institute.

[*Proceedings of the stated meeting, held April 20, 1892.*]

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, April 20, 1892.

Mr. G. MORGAN ELDRIDGE, Chairman *pro tem.*

Present, forty-six members and five visitors.

Additions to membership since last report, eight.

The Secretary reported the death of Mr. Wm. A. Cheyney, auditor of the Institute, and moved the appointment of a committee to prepare a suitable memorial of the deceased. Carried.

Mr. E. H. Outerbridge, of New York, gave a description of a new article of manufacture, called "pantasote" leather, designed principally to serve as a substitute for leather, and especially for the more costly varieties of leather employed for upholstery, wall decorations, travelling bags, etc. The speaker illustrated his remarks by the exhibition of a series of lantern slides showing the process of manufacture, and of an interesting suite of samples of the finished products.

Mr. Thomas P. Conard presented a description, with lantern projections, of the Shay geared locomotive.

Mr. T. F. Cook, of Tacoma, Washington, followed with a description of a new method of transportation recently invented by him. The inventor employs an overhead system, the permanent way consisting of a single line of columns carrying an upper and lower girder. The invention consists further in an arrangement of horizontal pulleys which are carried on the lower girder, adapted to be driven by any suitable motive-power and by which motion is communicated to the cars. The latter are arranged to travel in opposite directions on the two sides of the elevated structure.

The Secretary read his monthly report.

Adjourned.

WM. H. WAHL, *Secretary*.

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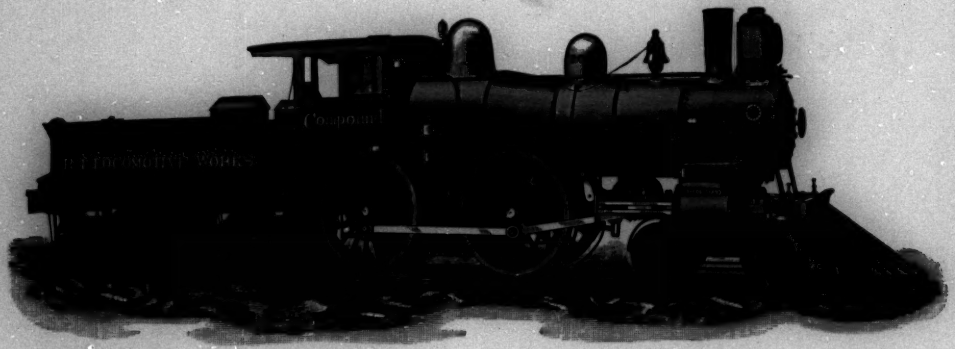

COMPOUND LOCOMOTIVE—Built by the Rhode Island Locomotive Works, Providence, R. I.

JOURNAL

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OF THE STATE OF PENNSYLVANIA.

FOR THE PROMOTION OF THE MECHANIC ARTS.

VOL. CXXXIII. MAY, 1892. SUPPLEMENT

THE Franklin Institute is not responsible for the statements and opinions advanced by contributors to the *Journal.*

THE COMPOUND LOCOMOTIVE OF THE RHODE ISLAND LOCOMOTIVE WORKS, PROVIDENCE, R. I.

[*Report of the Committee on Science and the Arts, with Appendices.*]

[No. 1,610.] HALL OF THE FRANKLIN INSTITUTE, PHILADELPHIA, January 30, 1892.

The sub-committee of the Committee on Science and the Arts, constituted by the Franklin Institute of the State of Pennsylvania, to whom was referred, for examination,

THE COMPOUND LOCOMOTIVE OF THE RHODE ISLAND LOCOMOTIVE WORKS.

Report, That in order to set forth the merits of this invention it has had submitted to it a record of a series of tests made under the supervision of Mr. C. H. Batchellor, chief draughtsman of said works, together with copies of

diagrams and descriptions of the engines under test, which records accompany this report, and are as follows:

The engines are of a type known as two-cylinder compounds; that is, such as use the steam first in a small or high-pressure cylinder, on one side of the engine, and exhaust through a connecting pipe, within the smoke box, into the steam chest of a larger low-pressure cylinder on the other side, in which cylinder the steam is further expanded and from which it is finally exhausted through a blast pipe into the chimney in the usual way.

To this connecting pipe or receiver, between the two cylinders, is joined (forming part of the same) an automatic intercepting valve, to which is also attached an automatic differential pressure-reducing valve, an exhaust valve, and a controlling valve worked by hand in the cab. The valves constitute the essential features of this invention.

The object of this invention is to provide means whereby the engine may be started and run continuously with steam directly from the boiler, in both cylinders, each doing half the work, and each exhausting into the stack and atmosphere directly. At the will of the engineer the engine may be changed into compound-working, these valves and steam-ways being designed to effect this object automatically, according as the engineer moves the lever connected with the controlling valve.

These improvements are the invention of Mr. C. H. Batchellor, and patented by him September 22, 1891, full specifications of which accompany this report.

The operation and effects of the intercepting valve and its auxiliaries may be described as follows:

This valve being in any position and the throttle being opened, boiler steam will pass to the high-pressure cylinder in the usual manner, and also through a branch pipe to the intercepting valve, into the space between the two smaller pistons fixed on one end of the valve stem, causing the pistons to move from this end towards the larger of the two pistons, by which communication for steam is established through the inter-piston space to a pipe leading through an automatic reducing valve, and thence into the low-pressure

steam chest, the pressure being reduced from any existing boiler pressure in the ratio of the cylinder areas. This position of the intercepting valve closes the low-pressure steam chest against a flow of steam from the receiver.

The three pistons on the valve-stem of the intercepting valve are so proportioned that they will automatically change to the compound position, when the pre-determined pressure in the receiver has been reached by exhausts from the high-pressure cylinder; the engine thus starts with steam in both cylinders and automatically changes to compound at a desired receiver pressure.

The engine may be changed from the compound system to the simple at any time, at the will of the engineer, by opening a valve connecting the receiver to the exhaust pipe, allowing the exhausts of the high-pressure cylinder to be ejected through the exhaust nozzles in the usual manner. The operation of this exhaust valve permits receiver pressure to enter the smaller end of the piston chamber of the intercepting valve, in order to insure the movement of the piston to that necessary to permit the boiler steam to enter the low-pressure cylinder, and close the receiver against the same, and to do this before the receiver is emptied through the exhaust.

This insures against a lapse of continuous action in the low-pressure cylinder, during the change from the compound to the simple system while running.

It is obvious that, in case of bad conditions of starting, the engine may be operated as a simple one at the will of the engineer, by opening the exhaust valve before starting, and that upon its closure the pistons will automatically take the compound position as already described.

The motions of this intercepting valve are controlled by a fluid piston brake, so that it cannot be moved except by a force superior to the fluid resistance, which the steam supplies, and it is inert wherever placed.

This engine differs from all other two-cylinder compound locomotives in this country, in having a means provided by which the engine may be worked just as a simple engine is, with an independent exhaust from each cylinder

This arrangement provides sufficient power at starting and under any condition of service for a period of time, or a distance from the starting point, which is at the will of the engineer.

This type of compound can be run as a simple engine in case of break-downs, with no more trouble than an ordinary engine.

In point of cleanliness, *i. e.*, freedom from cinders and black smoke, the compound offers a marked contrast to the simple engines.

The fastest and hardest work has called but for the most ordinary care in the lubrication of parts; one of them on trial (called No. 2600), has never shown a suggestion of heating in any of the bearings or journals, all of which are of the ordinary size, and this engine has so satisfactorily met all the requirements of heavy and fast express service that have been placed upon it for several consecutive months, that the builders believe themselves justified in claiming as a conservative estimate a saving of fifteen to twenty-five per cent. of fuel, in express service, in competition with a simple locomotive, the amount of saving depending upon the service.

These improvements can be applied to existing simple locomotives.

The slide valves are operated by Stephenson's link as applied to locomotives generally.

The possibility of using this engine as a simple one indefinitely, is also a very desirable adjunct for yard work, or short runs with many stops.

As an illustration of the softness of the blast, due to the low tension of the escaping steam after continued expansion in both cylinders, the engine practically throws no sparks during the hardest service, even with a clear passage from the boiler tubes to the atmosphere.

The application of steam power to the bearings of a compound engine is more evenly distributed than in simple ones, as is well known, which must contribute to smooth and easy running in a locomotive. This effect is apparent in the several graphical illustrations shown in this report,

which speaks largely in favor of better stress effects when compared with the performance of the simple engine in same service.

We have here the most scientific development of a two-cylinder compound engine, automatically adapted to all requirements of variable service.

Your sub-committee, having examined the mechanisms and applications of these improvements in detail, as well as all the disinterested records of the same at its command, and having carefully noted and compared the devices and claims therefor, of other inventions for a like purpose, concludes this report by recommending the award of the ELLIOTT CRESSON MEDAL to Mr. C. H. Batchellor, for his invention.

JOHN H. COOPER, *Chairman*, H. R. HEYL,
JOHN E. CODMAN, H. F. COLVIN,
LUTHER L. CHENEY.

Adopted, February 24, 1892.

ARTHUR BEARDSLEY,
Chairman of the Committee on Science and the Arts.

APPENDIX I.

COMPOUND LOCOMOTIVE OF THE RHODE ISLAND LOCOMOTIVE WORKS, PROVIDENCE, R. I.

In the following pages is given a description of the mechanism employed in the operation of the two-cylinder compound locomotives, built by the Rhode Island Locomotive Works; also the data and results of comparative tests regarding the economy and general efficiency of these locomotives as compared with ordinary locomotives, in the following services, each contained in a section of the folio.

SECTION 1.—ELEVATED SERVICE.

Gives the data and results of a comparative test between two locomotives in elevated railroad service; the compound locomotive being a duplicate of the simple one with new cylinders.

SECTION 2.—EXPRESS PASSENGER SERVICE.

Gives the data and results of comparative tests between different simple locomotives and a compound locomotive built by the Rhode Island Locomotive Works for fast express service.

Serious doubts having been commonly expressed as to the ability of the compound to cope advantageously with these two classes of service, this folio is prepared as the most concise and complete method by which the numerous questions concerning actual results can be answered. All results are from data verified by the respective railroad companies.

SECTION 1.—ELEVATED SERVICE.

Description of Engines.

The engines compared are No. 62 Simple and No. 58 Compound, of the Brooklyn and Union Elevated Railroads of Brooklyn, N. Y. (A synopsis of sizes is given in Table 1.) Both engines were of the Forney type, having two pairs of connected driving wheels, with a four-wheeled, trailing, swing truck supporting the tank, the whole connected to a rigid frame. This design is used to run forward or backward at will.

The compound engine was a simple engine rebuilt by the Rhode Island Locomotive Works, so far as the cylinders and their appurtenances are concerned, and is of the two-cylinder type, the cylinders being connected by a copper receiver. The cylinder sizes of the compound were designed to do the average service work, so near as it could be judged, with the best economy. The limitations which the size of compound cylinders, designed for this effect, must necessarily bring upon the starting, or even the hauling power of the engine under exceptionally severe conditions, is recognized and provided for by a device allowing the engine to be run at will as a simple engine: the steam pressure in the low-pressure cylinder being reduced from that in the high-pressure cylinder in direct ratio of the

piston areas, irrespective of the boiler pressure. This allows the compound to be used as a simple engine, and greatly increases its maximum power; this becomes necessary in emergency cases only. The possibility of using the engine as a simple engine indefinitely is also a very desirable adjunct for yard work, allowing the engine to be worked to much better advantage. In ordinary circumstances the engine starts from rest as a simple engine, with direct steam in both cylinders, the cylinders having equal power. When the normal pressure in the receiver is reached, by means of the exhaust from the high-pressure cylinder, the direct steam is automatically cut off from, and the receiver steam admitted into, the low-pressure cylinder, and the engine thus thrown into the compound system. There is thus no appreciable change in power when the change from simple to compound is made, either in changing automatically or on being changed from the cab. The automatic change occurs from one-half to one revolution of the drivers. For actual performance in this respect see indicator cards, *Plates XXIII* and *XXVII*, inclusive.

SERVICE.

The service for which the engines under consideration were designed is of a severe nature for locomotives of ordinary form, and is considered much more so for a compound locomotive, being a series of starts and stops in quick succession, the profile containing many grades and sharp curves; prompt running time being indispensable. The total length of the division on which the engines were run is five miles, divided into sixteen passenger stations and two junction stations, at which stops were required at the time the compound was run on account of a rule issued between October 15th and November 24th. Trains consist of two cars during the middle of the day and late at night, and three or four cars during morning and evening hours. The running time is twenty-four minutes, with a headway of six minutes between trains during the two-car trips and five minutes during the four-car trips. See Table 2 for the number of cars hauled each trip, and the running time each day of the test.

CONDITIONS OF TEST.

The compound engine was run November 24, 1890; the simple, October 15, 1890. The engines were started from the yard at East New York at 6.15 A.M., and run six miles, with a light four-car train, to Fulton Ferry, where they commenced service, making twenty-two trips (eleven round trips) of five miles each, from Fulton Ferry to Ridgewood and return; then one trip of four empty cars to East New York, six miles, making a total train mileage of 122 miles from 6.15 A.M. to 8 P.M. The running time was kept by one watch, time being taken at each terminal; the duration of stops at regular and signal stations was not taken. They averaged about the same, both days being pleasant, the rail good, and the locomotives under trial not being held at signal stations to any unusual extent. The trip at 6.12 P.M., on November 24th, however, was an exception, trains being delayed seven minutes in the busiest part of the day, by awaiting the movements of an extra engine. This necessitated the hand-

ling of the exceptionally large number of passengers who had congregated, and required extra time at stations.

CONDITION OF ENGINES.

Simple engine No. 62, together with its crews, was selected by the railroad company as being the most economical on the road, as judged by performance sheets and competitive trials. The engine seemed in good condition, with the exception of the safety-valve, which leaked enough to show steam to a limited extent. The blow-off cock also leaked water; this was measured and accounted for.

Compound engine No. 58 had new metallic packing and leaked badly at the left valve stem. The throttle also leaked considerably.

MANIPULATION OF THE ENGINES AND PERSONS CONCERNED.

The crew who handled the simple engine were Mr. James Giles, engineer, and S. A. Sampson, fireman. These men formed part of the double crew who had handled it from the time it came on the road, and together with the other crew had demonstrated their expertness in economic running. Mr. Giles being off duty, the compound was handled by Mr. H. N. Fessenden, who ran in conjunction with Mr. Giles on the simple engine. Mr. Sampson did the firing. The management of the engines left nothing to be desired. The compound had been in their hands about ten days before the test was made, and was run entirely by the reverse lever until the first notch was reached, the throttle being kept wide open. The blower was used but once or twice on the compound, and sparingly on the simple. No. 58 was always worked compound automatically while in service.

COAL CONSUMPTION.

Weighed coal was used as follows: A new fire was used on both days, the tank was cleaned and weighed coal put in. The fire was built the night before and banked from coal outside the tank. When the fireman fixed his fire for running about 5.30 A.M., he used coal out of the tank, and continued so to do until the yard was reached at 8 P.M., when the condition of the fire was noted and the coal left in the tank weighed back. The state of the fire and steam pressure was similar each day at time of using first weighed coal. Each bucket of coal was weighed by an employé of the Railroad Company. It was all of the same quality and was free from dirt. The size of the coal was broken lump, and was of a soft anthracite quality. The coal was not wet during the test. The fire was well burned out at the end of each day, especially so on October 15th. The ashes were not weighed, circumstances not admitting of it. They showed a very small per cent. of unburnt coal each day. The compound burned its fires with a light draft on all trains. Steam was made very freely, the door being on the latch frequently, even with heavy trains, and especially so with light trains. Engines of the simple class steam freely with a light fire on light trains, but on the three and four-car trains the blast is sharp and fires heavy in order to keep up steam. The compound makes steam with a draft so light and even that it would seem able to

burn pea coal with good steaming results, and a further saving in fuel expense. The quality of coal used breaks up immediately on contact with fire; and on regular engines quite an item is lost through the stack in a bright, unburnt condition, in small particles. Quantities can be seen in all places along the road where it can lodge; this dirt becomes disagreeably apparent when standing on the car platforms. The stronger the blast, the more this effect. Spark-throwing is also prevalent to quite an extent in heavy business hours. The soft blast on the compound does away with much of the waste mentioned, and throws practically no sparks on the hardest service. Continued observations on car platforms were conclusive as to the cleanliness of this engine in regard to dirt through the stack. As an illustration of the softness of the blast, it may be remarked that there was nothing in the smoke box of the nature of deflecting plates or netting, a clear passage being left from the tubes to the atmosphere. For details and summary of comparative coal consumption, see Table 2.

WATER CONSUMPTION.

The water was measured as follows: A barrel was measured as to capacity, and then placed in position so that it could be filled and emptied into the tank readily until the tank was full, the height of water in the tank being taken after each barrel full. Each barrel full made an equal rise of water in the tank, showing the regularity of the tank capacity in height. The various readings of water consumed were made by means of a large float, to the centre of which was attached a graduated stick. The difference in any two readings on this stick when compared with top of man-hole, gave the amount of water used for that time in inches. The readings were made at about the point of the centre of gravity of the plan of the tank, and always at the same place on a level track. The first reading was made in the morning at the time the first weighed coal was used, with the water in the boiler just showing in the third gauge. When the yard was reached at night, the water was gauged with the same amount in the boiler, and the same pressure of steam as at the start. During the day the water was measured each round trip at Fulton Ferry, where water and coal were taken, the water being kept at the same point in the boiler at each time of measuring. After leaving the yard in the morning, the water in the boiler of the compound engine was allowed to fall to the second gauge, and was kept there through the day to insure dry steam. On the simple engine the water was kept at three gauges through the day. The overflow from the injectors on each engine flowed into a receptacle and was measured. Each reading on the gauge stick was checked by the engineer or fireman. For details and summary of comparative water consumption, see Table 2.

CYLINDER PERFORMANCE.

Indicator diagrams illustrating the cylinder performance under the varying conditions are attached. They are taken from a series of cards made on a surface road just before the engine was placed on the elevated structure, and are each typical of its class. They were made during a run

of twenty-seven miles between Providence and Kingston on the New York, Providence and Boston Railroad, with a miscellaneous freight train.

A three-fourths-inch pipe, eleven inches long, from each end of each cylinder, was connected to the indicator by a three-way cock in such a manner as to avoid abrupt turns, or small apertures; these connections were well wrapped with asbestos.

The cross-head motion was reduced by a special device of the pantograph type, calling for a string connection of but a few inches in length.

The pistons of the indicator were carefully watched and lubricated, and no signs of sticking are visible on the cards. The cards were all taken with a No. 80 spring.

The speed was taken with a revolution counter of positive action in the cab, the motion being taken from the pantograph. The steam gauge and indicator springs were tested before the cards were taken.

The valve motion is the ordinary Stephenson link as applied to locomotives generally, except the direction of its motion is reversed, the eccentrics being on the forward axle pointing toward the rear or main axle, with short eccentric rods. This was a feature that had to be contended against in endeavoring to get equal cut-offs and openings for the valves in all the various positions. For valve dimensions, etc., see Table 1.

The operation of taking a set of cards was as follows: There was a man at each indicator and a man in the cab. The latter at a desired time gave the indicator men a signal to be ready, and threw in the catch to the counter; he then gave a signal on the whistle at which the cards were taken simultaneously from each cylinder. The steam gauge and notch were noted, and at the end of ten seconds the speed counter was detached, and a reading taken. The speed was thus taken while cards were made, and cards were as near simultaneous as possible.

Steam chest lines were not taken on this day, it being desirable to use the shortest possible time in taking cards, and a previous trial having shown steam chest lines satisfactory. Cards showing these are shown on *Plates I*, *II* and *XXIX*.

Plates I to *XX*, inclusive, have each a set of high- and low-pressure cards, traced with the atmospheric line in common; and also a combined diagram showing the continuous expansion associated with hyperbolic expansion (full smooth curve), and with the expansion of dry saturated steam (dotted smooth curve). In the combined diagram, the front and back end cards are represented by full and dotted lines. Cards shown on *Plates XXI* and *XXII* were taken with the engine working upon the simple system. The speed at which cards 25 and 42 were taken is far in excess of what would be required, the simple system being desirable only in starting heavy trains, or running them under exceptionally hard conditions at slow speed. In these cards the admission line to the large cylinder shows the operation of the reducing valve to limit the initial pressure to a proper proportional amount, but the boiler pressure admission pipe to the large cylinder not being large enough to satisfy these

speeds, the steam was wire-drawn, which gives the difference in M. E. P. between the two cylinders, as figured on the cards. The contour of the cards from the large cylinder, however, shows the proper reduction of initial pressure which the reducing valve secures at a considerable piston speed, which was the object of taking the cards at the given speeds. *Plates XXIII* and *XXVII*, inclusive, show cards made with the engine starting from rest; of these *Plates XXVI* and *XXVII* simply show the action of the reducing valve in keeping the total admission pressure on each piston alike and constant while it is acting. *Plates XXIII* and *XXV*, inclusive, show the above action and also the time of the automatic action in changing to the compound system, showing the difference in pressure in the receiver at the time of the change and a revolution later.

Plate XXVIII has cards illustrating revolutions made by an ordinary compound engine after the throttle is shut, before the passages are freed from pressure, when the reverse lever is in the last notch. In yard work this is a hindrance, and is undesirable at any time, when it is necessary to stop before the engine can clear itself of steam. This can be obviated by the use of the device which allows this engine to be used as a simple engine.

Table 3 contains results from thirty-eight cards, tabulated for easy reference. This table includes the steam weight accounted for by the diagrams; and is arranged consecutively in order of the different notches and speeds. The cards are from the same lot from which those illustrated were taken, and includes them. This table offers an opportunity to compare the difference in cylinder economy between high- and low-pressure steam under similar conditions. It also shows the water consumption to vary but little through the varying speeds under like pressures of steam at the same cut-offs.

It is believed that the table and cards embody good general results, and show to good advantage in comparison with those from ordinary locomotive practice. The loss in pressure by the passage through the receiver is small for both slow and fast revolutions. The admission line is good, and the expansion lines of the different diagrams hold closely to the curve of saturated dry steam, tending to show a small amount of initial condensation. The water per horse-power per hour, which is the test of economy, figures low even on the cards doing work at fast speeds.

This low water rate for work done, shown by cards, is verified by the result of the actual service test, in which nearly twenty-four per cent. less water was used by the compound than by the simple engine in doing practically the same work for fourteen hours. The work done by each cylinder is practically alike at the third and fourth notches, and varies by degrees in opposite ways from that point, as shown by Table 3. The design was to have the point of equal power near the point of average work. This engine with light trains works in the first and second notches, and with heavy trains in the third and fourth notches, always starting from the seventh or last notch.

The low exhaust pressure shown on all cards, at the ordinary working

notches, is one cause of the water economy, and also signifies the style of action on the fire, these light exhausts occurring but twice a revolution in place of four times.

STRESS EFFECTS.

Aside from the economy in fuel and water consumption, an important result of the difference in cylinder performance between a simple and compound locomotive, under similar conditions, is that the latter should bring to bear upon the moving parts a more continuous or even stress, while subjecting those parts to loads of less magnitude at the point of maximum stress. The effect of the applied power should also be more regular in the compound engine. As illustrative of this effect, graphically, diagrams on *Plates XXX* to *XXXIII*, inclusive, give the rotative effect on each crank pin, together with the resultant effect for one revolution. The data taken for a simple locomotive, in working up these diagrams, are actual cards selected from first-class locomotives having Richardson-Allen valves, and a good steam distribution. Those for a compound are taken from No. 58, with initial pressures and M. E. P.s' to match the cards from the simple engine. These plates explain themselves, and suggest a steadier moving engine, more especially at high speeds, and the shortest cut-offs.

Plates XXXIV and *XXXV* show diagrams made from the same data, illustrating graphically the stress upon the crank pins, and hence the other moving parts, for one revolution. It will be observed that the lines representing the stresses on the compound crank pins keep within closer vertical limits than those on the simple engine, also, that the former keeps much nearer a continuous line, sudden variations in load being inappreciable.

GENERAL SUMMARY.

A reference to Table 2 shows the decided saving in water and fuel consumption, under the conditions of a fourteen hours' test heretofore described; this would be anticipated from diagram results in Table 3. Aside from the first cost and labor of handling this saving affects the time lost by the engines in coaling and taking water. The latter is of evident value on limited trains. In the elevated service it enables, in many cases, an engine which reaches the terminal late to save the time that would otherwise be used in taking water, thereby preventing the following train from being held by a signal. This was a fact noticed and commented upon by the train despatcher at the terminal where water and coal were taken.

The capabilities of the compound to equal the simple engines, in making short runs, on quick time, were fully demonstrated. This compound, by reason of its ability to be run at will as a simple engine, can equal the maximum power of a simple engine, when the small cylinder on the compound equals in size each of those on the simple, and the steam pressures are alike.

The smoothness of running on the compound, as compared with the simple, is noticeable in riding on the engines. This is explained by a com-

parison of the resultant rotative effects on the crank pins for the different systems, as illustrated graphically, with data, in *Plates XXX* to *XXXIII*, inclusive. This is a very desirable result as it affects the connections through the whole train.

The crank pins and reciprocating parts are not subject to such high pressures or sudden variations in stress during each half stroke in the compound, a result greatly to be desired. A comparison of stresses on the two systems, with data, is graphically illustrated in *Plates XXXIV* and *XXXV*.

Cylinder oil can be used with the best economy in the compound engine, the oil fed to one cylinder passing through both.

The cleanliness of the compound from cinders and sparks is a strong point in its favor. Its comparative stillness is also another desirable factor under certain conditions of service.

SECTION 2—FAST EXPRESS SERVICE.

Description of Engines.

The compound locomotive (No. 2600) was designed for making fast time on trains with few stops; and for a road with a level or rolling surface; the idea being to test its merits on this class of service against the ordinary type of express locomotives.

The engines used in competition with No. 2600 were No. 34, New York, Providence and Boston Railroad, and engines Nos. 136 and 173, Boston and Albany Railroad; the latter two being similar engines. The main dimensions of all three are found in Table 4 following. An inspection of these tables will show that the engines were very similar, the compound having very little advantage in heating surface, and a disadvantage in tractive power which counted against it on the heavy grades of the Boston and Albany Railroad, work for which this engine was not designed.

The action of the compound engine in starting and changing automatically to the compound system, and also the ability to run as a simple engine, are the same as described under Section 1.

Illustrations of the auxiliary and intercepting valve are shown in *Figs.* 1, 2 and 3.

SERVICE.

No. 2600 has been in successful general service on all the heavy and fast trains on the New York, Providence and Boston Railroad, between Providence and New London, a distance of sixty-four miles. The terminals are at tide water, and the intervening road has a rolling surface, there being grades each way from one-half to one per cent. The line of road is practically straight. Tables 5 and 6 give the results of competitive trials on two of these trains; that represented by Table 5 was made to show coal economy only.

The service on the Boston and Albany Railroad was between Boston and Springfield, a distance of ninety-nine miles, and was of a different nature from that on the New York, Providence and Boston Railroad, This will be seen on reference to the profile sketch following, the steepest

grades on this road having bad curves. In making the schedule time between the terminals, advantage cannot be taken of the down grades to the extent of over forty-two miles per hour; and the making up of lost time is limited to five minutes each between Worcester and Springfield and Worcester and Boston; thus the time which an engine designed for a more level road might lose on a bad up-grade could not be made up on the down-grades, and but five minutes could be made up on the levels. In order to make the running time, therefore, little time can be lost on the hills. The compound, as before-mentioned, is not designed for this class of service, but, as will be seen on reference to Tables 7 and 8 following, it had no difficulty in making its time with the other engines. Its ability as a hill climber was fully recognized after its experience with these trains. This was due to its excellent staying qualities when worked to full capacity as a compound, together with its ability to get under way quickly from a bad starting place as a simple engine.

CONDITIONS OF TEST.

The competing engines on each trial were run on the same trains, the same number of days, with the conditions as nearly alike as possible, the same engineer handling each engine, enough days being taken to insure a fair average. The engineers had no experience with the compound previous to the first day of each test; but were regular runners on the competing simple engine, with the following exception: On the trial of March 16th to 21st, inclusive, the engineer had No. 34 but a few days before the test. The runs on the Boston and Albany Railroad were exceptionally hard for each engine, as the road was undergoing repairs in numerous places between Boston and Springfield, which necessitated many slow-ups and extra stops.

On the New York, Providence and Boston Railroad, the conditions were very similar for each engine on each trial, with the exception of the runs on March 20th and 21st, recorded in Table 5. On these dates the train, being an hour late from New London, was obliged to make extra station stops, besides stopping for several signals, and slowing up for the suburban trains at stations near Providence. This affected the elapsed time between New London and Providence and also the general average of running time.

COAL AND WATER CONSUMPTION.

The coal economy, as given in Tables 5 to 8, inclusive, is based on car mileage. The results are practically the same when based on ton mileage. Coal was weighed to the engine at the beginning of each trial, there being a low fire and no coal on the tank; that used by each engine includes the banking for over night. At the finish of the last run of a series, the fire was allowed to burn low, and the remaining coal in the tank was weighed back. The coal account, in all cases, was kept by an employé of the railroad company.

The quality of coal on the New York, Providence and Boston Railroad was ordinary bituminous, about one half lumps.

The coal used on the Boston and Albany Railroad was best quality of Pocahontas, well mixed with lumps.

Accurate water measurements were attempted on but one test, objections being made to the delay incident to taking accurate readings when water is taken on the line of the road. From the observations which were made, however, there is every reason to believe that the trial in which the water was measured was the one in which least was saved. This would follow from the fact that it was the lightest of the four tests in point of work done, and that in which the least coal was saved.

On the test in which water was measured, careful attention was paid to the measuring of all quantities not used in the cylinder, and high water in the boiler was guarded against. The water in the boiler water-glass, was at the same place when final tank reading was taken at the end of the round trip, as when the first reading was made, the engine standing at the same spot.

CYLINDER PERFORMANCE.

Indicator diagrams were taken from No. 2600, in Section 1; and the diagrams shown in *Plates I* to *XXIX*, inclusive, fairly represent those taken from No. 2600 under the same general conditions, the ratios of cylinder areas being the same in each case. The cylinder powers show very nearly equal.

Plate XXI shows diagrams taken for experimental purposes as explained in Section 1.

Plate XXII shows diagrams taken in the simple system, the conditions being the same as those under which it is designed to be used when run as a simple engine. No. 47, on this plate, was taken at an early cut-off to show the action at that point.

GENERAL SUMMARY.

A reference to Tables 5 to 8, inclusive, will show the saving in fuel consumption made by the compound, on each given service, running in competition with selected engines on the respective roads; the engineer in each case being the regular runner of the simple engine, but handling the compound for the first time. The engineers all claimed that they could do more justice to the compound on a longer acquaintance.

All the engines were as nearly alike as was possible under the circumstances, the cylinder action excepted; and the differences in heating surface alone were too small to affect appreciably the fuel consumption.

The compound has met satisfactorily all requirements of hard work and fast running that have been placed upon it.

In point of cleanliness, *i. e.*, freedom from cinders and black smoke, the compound is a marked contrast to the simple engines. This feature was quickly observed and remarked by the engineer and trainmen on the first trips on each new train. From this fact the question naturally arises why the compound could not be substituted for the large and heavy anthracite coal burners which are run at large expense and considerable trouble

on some fast trains simply on account of the item of cleanliness. No. 2600 needs and has no netting in the smoke-box.

If the compound locomotive can be run so that the smoke and cinder nuisance is satisfactorily dispensed with, which would seem to be the case, the cost of operating it as compared with an anthracite coal burner may be illustrated from an actual case as follows: Trains 23 and 42, New York, Providence and Boston Railroad (see Table 5) have an anthracite locomotive for a regular engine; it runs 29·5 miles per ton of coal as a regular average. Another anthracite locomotive on a somewhat lighter service on the same road runs 30·5 miles per ton. Comparing the cost of anthracite fuel on trains 23 and 42, with the cost of bituminous fuel used by the compound on same trains (forty-two miles per ton), the saving in cost is forty-eight per cent., the bituminous coal costing twenty-six per cent. less delivered than the anthracite.

It is claimed that in a properly designed compound locomotive, the stress effects of the reciprocating and revolving parts should be more regular than in a simple engine, exerting the same power. (See Stress Effects, Section 1.) No. 2600 has never shown a suggestion of heating in any of the bearings or journals, all of which are of the ordinary size. The fastest and hardest work has called for but the most ordinary care in the lubrication of parts. The voluntary verdict of all the engineers is that it is an uncommonly cool running locomotive, light on oil, and easy to take care of; the latter in their estimation being quite a point in favor of the compound.

The ability of this type of compound to be run as a simple engine enables it to be run with either cylinder singly, in case of break-downs, with no more trouble than an ordinary engine.

No. 2600 has so satisfactorily met all requirements of heavy and fast express service that have been placed upon it for several consecutive months, that the builders believe themselves justified in claiming, as a conservative estimate, a saving of fifteen per cent. to twenty-five per cent. fuel on express service by a properly proportioned compound of this type, in competition with a simple locomotive, the amount of saving depending on the service; also a decided advantage in cleanliness; and freedom from heating tendencies, the latter signifying light oil consumption.

— PROFILE SKETCH —

RIDGEWOOD LINE

— OF THE —

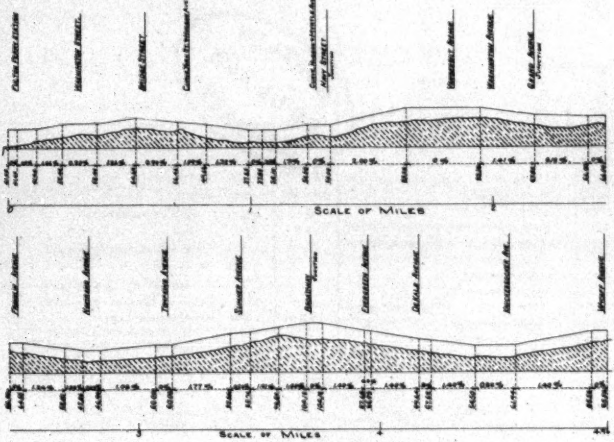
UNION ELEVATED R.R.

FULTON FERRY STATION TO WYCOFF AVENUE

— BROOKLYN, N.Y. —

HORIZONTAL SCALE 1IN.=1500FT

VERTICAL SCALE 1IN.=150FT.



— PROFILE SKETCH —

BOSTON AND ALBANY R.R.

— BETWEEN —

SPRINGFIELD AND BOSTON

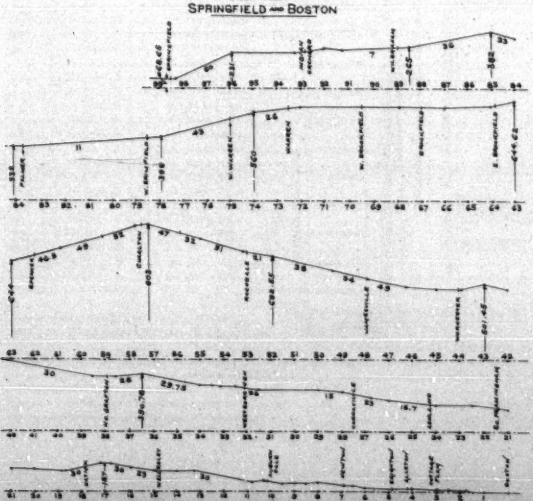


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TABLE Nº 1

LOCOMOTIVE DIMENSIONS.

TYPE	COMPOUND	SIMPLE
FUEL	ANTHRA COAL	ANTHRA COAL
CYLINDER-SIZES-R.S.	18"×16"	11"×16"
" " -L.S.	11½"×16"	11"×16"
" -PORTS-STEAM-R.S.	1"×17"	⅞"×8½"
" " -L.S.	¾"×10"	⅞"×8½"
" " -EXHAUST-R.S.	2"×17"	1¾"×8½"
" " -L.S.	2"×10"	1¾"×8½"
" -CLEARANCE-R.S.	10.2 %	8 %
" " -L.S.	11 %	8 %
STEAM PIPE FROM BOILER-R.S.	2" DIA.	3" DIA.
" " " " -L.S.	3½" "	3" "
PISTON ROD DIAMETER	2"	2"
DRIVERS-DIAMETER	42"	42"
" -REVOLUTIONS PER MILE	480	480
BOILER - DIAMETER	42"	42"
" - FLUES - O.D.	1½"	1½"

TYPE	COMPOUND	SIMPLE
BOILER - FLUES - NUMBER	124	124
" " - LENGTH	66⅜"	66⅜"
EXHAUST TIP DIAMETER	3"	3¼"
GRATE - STYLE	WATER GRATE	WATER GRATE
" - SIZE	54⅜" × 41"	54⅜" × 41"
" - AREA	15.6 SQ.FT.	15.6 SQ.FT.
HEATING SURFACES - TOTAL	2894.6 "	2894.6 "
" " - FIREBOX	454.6 "	454.6 "
" " - FLUES	2440 "	2440 "
AREA RATIO-HEATING SURFACE TO GRATE	185	185
STEAM CHEST VALVE - STYLE	BALANCED	BALANCED
" " " - FULL TRAVEL	5"	5"
" " " - LAP OUTSIDE	FP. ⅞" : 2. 1"	⅞"
" " " - CLEARANCE	FP. 1/16" : 1/2"	1/2" LAP
WEIGHT - LOADED	45850 LBS.	45350 LBS.
" " - ON DRIVERS	31534 "	31034 "
" " - ON TRUCK	14316 "	14816 "

TABLE Nº 2

GENERAL DATA OF TESTS.

TIME		TRIPS	MILES	NPOU	CAR MILES	RUNNING TIME		COAL USED Cor.		WATER USED Cor.		WEATHER		CONDITION OF ENGINES		REMARKS
'82	'88	'82 - '88	'82	'88	'82	'82	'88	'82	'88	'82	'88	'82	'88	'82	'88	
6.55	6.35	1			1140	14-55										
6.55	6.35	ENTIRE	6	4	24	35—	00—	1005			550	471				
7.01	7.01	1														
7.01	7.04	To RIDGE	5	4	20	24—	26—									
7.58	7.58	1														Error Shown Adj. '88 Terminal Run '82
8.48	8.48	To F.F.	5	4	20	25—	26—				1062	1018				
8.48	8.48	1														
9.43	9.40	To RIDGE	5	4	20	22½	25—									
9.43	9.43	1														Error Shown Adj '88 Terminal Run
10.38	10.41	To F.F.	5	4	20	23—	25—				2842	1978				
10.38	10.41	1														
11.33	11.33	To RIDGE	5	4	15	22—	24—									
11.33	11.33	1														
10.15	10.18	To F.F.	5	2	10	22—	24—			500	2277	1787				
10.30	10.32	To RIDGE	5	2	10	23½	23½									
10.47	10.47	1														
10.47	10.58	To F.F.	5	2	10	23½	23½				1811	1429				
11.21	11.23	1														
11.58	11.58	To RIDGE	5	2	10	23½	23—									
12.08	12.06	1														
12.45	12.45	To F.F.	5	2	10	24—	24—				1593	1246				
12.50	12.57	1														
12.58	1.01	To RIDGE	5	2	10	23½	24—									
1.10	1.08	1														
1.34	1.30	To F.F.	5	2	10	24—	23½	500			1818	1428				
1.45	1.45	1														
2.02	2.04	To RIDGE	5	2	10	24—	24½									
2.58	2.16	1														
3.30	3.40	To F.F.	5	2	10	23½	24—			500	1767	1802				
3.50	3.48	1														
4.15	4.16	To RIDGE	5	2	10	23—	24—									
4.23	4.23	1														
4.53	4.54	To F.F.	5	2	10	24—	23½	500			1870	1502				
5.01	5.03	1														
5.28	5.28	To RIDGE	5	2	10	23½	24—									
6.01	6.06	1														
6.28	6.28	To F.F.	5	5	15	24½	25—	500			2089	1890				Error Shown Adj '88 Terminal Run
6.58	6.58	1														Error Shown Adj '88 Terminal Run
7.40	7.40	To RIDGE	5	4	20	25—	26—									
8.27	8.40	1														
8.41	8.48	To F.F.	5	4	20	24—	25—	196			2812	1944				
9.41	9.12	1														
9.41	9.41	To RIDGE	5	4	20	29—	24—									Less Note Page "4" In Regard To Delay
9.58	9.58	1														
2.05	2.10	To F.F.	5	5	15	23½	23—	68			2768	1899				
2.43	2.51	1														
2.58	2.58	To RIVER	5	4	24	24—	24—				721	1178				
TOTALS		24	132		960			2499	2430	8700	7068					

RESULTS

GAIN IN FUEL OVER '82. AV. FOR DAY - 27.7%	TONNAGE EQUIVALENT AV. DR. PER POUND FUEL IN '82 AV. AT 160 LBS PER WAGON = 0.64 LBS
AV. COAL PER CAR MILE FOR DAY '82 - 11.08 LBS	TONNAGE EQUIVALENT AV. DR. PER POUND FUEL IN '88 AV. AT 150 LBS PER WAGON = 0.20 "
" " " " " '88 - 8.88 LBS	AV. WATER PER CAR MILE FOR DAY '82 = 7.388 LBS
GAIN IN WATER OVER '82 AV. FOR DAY - 29.8%	" " " " " '88 = 5.627 "
" " " " " 3.14 CAR TRIPS 26.1%	" " " " " 3.44 CAR TRIPS '82-88 GAIN
" " " " " 2 " 20.9%	" " " " " '88-88 "
EQUIVALENT AV. LBS OF WATER EVAPORATED IN '88 AV. 9.20 LBS	" " " " " 2 " '82-88 "
EQUIVALENT EVAPORATION FROM & AT 212° '82 - 8.68	" " " " " '88 GAIN
" " " " " '88 - 9.87	

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TABLE No 3
INDICATOR CARD RESULTS

Card No	Initial Pressure	Revs per minute	Notch and Cut-Off	Horse Power (IHP) HP	Horse Power (IHP) P	H.P. Ratio P/HP	Water per H.P. per Hour Account for by Indicator — In Pounds. HP Cut-Off	HP Release	P Cut-Off	P Release	Remarks
11	196	192		59.63	68.69	1.00	14.97	16.07	15.46	16.76	Experimental
10	196	192		64.75	73.33	1.14	16.19	18.64	15.68	18.56	Cards
47	193	246		72.45	80.18	1.24	17.35	17.77	16.91	18.54	
48	193	246		78.56	89.37	1.17	18.46	18.61	16.15	17.65	
7	115	270		60.62	74.91	1.17	19.92	19.66	17.68	19.98	
51	190	270		64.57	108.8	1.26	17.98	19.00	15.91	17.10	
50	193	282		81.41	108.6	1.27	18.96	19.03	18.39	18.57	
8	128	294		84.85	100.9	1.21	19.43	19.24	18.68	18.44	
45	128	300		70.58	93.69	1.33	19.91	19.86	19.23	19.84	
46	191	324		91.52	118.6	1.27	18.98	18.98	17.96	18.22	
25	117	120		76.97	61.21	0.80	—	—	—	—	Simple
6	119	228		78.07	94.93	1.22	19.82	19.02	18.80	18.81	
27	191	228		94.90	118.6	1.25	19.08	19.15	18.04	17.88	
53	192	258		98.58	116.1	1.22	19.78	20.25	18.59	18.88	
52	194	276		110.7	131.7	1.19	18.82	18.50	17.64	18.40	
9	191	282		106.8	125.6	1.17	19.29	19.42	17.82	18.67	
6	119	300		93.51	114.1	1.22	20.51	20.09	18.89	20.25	
10	191	318		107.8	134.1	1.24	19.81	19.68	18.62	20.18	
28	195	330		118.6	139.9	1.20	19.82	19.56	18.57	17.86	
19	149	180		107.1	109.2	1.02	19.31	19.65	17.79	18.08	
20	147	236		125.8	133.0	1.08	19.86	20.00	18.87	19.69	
11	138	276		127.1	142.1	1.12	21.08	21.06	19.94	20.98	
34	134	282		128.9	149.8	1.16	20.68	20.14	19.70	19.63	
12	130	306		127.6	140.5	1.10	21.84	22.04	19.60	20.79	
42	127	150		119.2	93.74	0.79	—	—	—	—	Simple
15	124	210		107.6	108.1	1.005	22.57	22.10	19.98	21.56	
43	120	228		108.5	116.8	1.07	22.28	21.96	21.19	21.96	
44	129	282		130.1	135.7	1.04	20.70	22.02	21.45	21.61	
21	141	270		149.6	152.7	1.02	22.51	22.44	21.25	21.56	
31	134	186		106.9	118.0	1.13	20.96	20.79	20.91	20.80	
22	145	210		138.2	137.8	0.997	22.21	22.08	21.42	21.22	
23	128	246		143.9	142.5	0.99	24.40	24.36	24.27	22.97	
1	136	180		74.07	86.77	0.98	22.80	22.75	20.97	21.01	
17	143	198		136.40	130.6	0.98	22.87	22.73	22.53	23.69	
33	148	222		155.09	158.8	1.03	22.80	23.27	23.16	23.60	
32	144	270		173.80	168.6	0.98	25.66	25.48	25.29	25.12	
27	136	180		122.0	114.1	0.96	24.98	24.68	24.22	24.47	
28	134	218		138.6	132.9	0.98	26.73	26.83	26.08	26.19	

No. 11. PLATE I.

U.E.R.R. ENG. No. 58.

Steam 163½ Rev. 192

Scale 80.

Av. M.E.P. { HP 33.16 / P 17.40 } Ref. to HP 42.63

TOTAL H.P. 122.12

R. I. Loco. Wks. ⅝ '90.

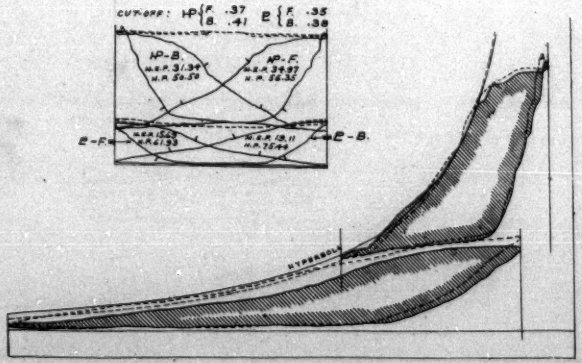

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PLATE II.

No. 10.

U.E. R.R. ENG. No. 58.

Steam 163½ Rev. 258

Scale 80.

Av. M.E.P. { HP 30.84 / E 14.95 } Ref. to HP 36.63

TOTAL H.P. 146.11

R.I. Loco. W'ks. '90.

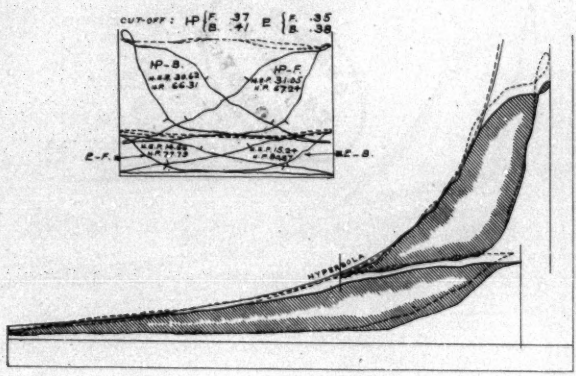

PLATE III

No. 47.

U.E. R.R. ENG. No. 58.

Steam 131½ Rev. 246.

Notch 1. Scale 80.

Av. M.E.P. { HP 35.09. / E 17.83. } Ref. to HP 43.68.

TOTAL H.P. 162.63

R.I. Loco. W'ks. '90.

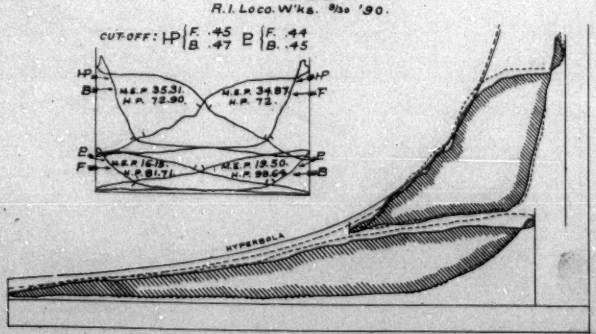

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PLATE IV

No. 51.

U.E.R.R. ENG. No. 58.

Steam 139. Rev. 270.

Notch 1. Scale 80.

Av. M.E.P. { HP 36.82 / E 19.15 – Ref. to HP 46.92.

TOTAL H.P. 190.9

R.I. Loco. W'ks. 3/00 '90.

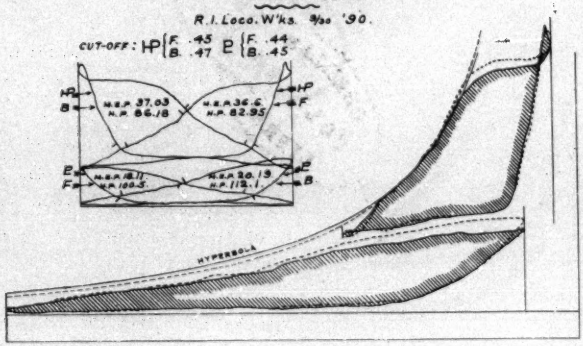

PLATE V

No. 46.

U.E.R.R. ENG. No. 58.

Steam 155. Rev. 324.

Notch 1. Scale 80.

Av. M.E.P. { HP 33.66 / E 17.46 Ref. to HP 42.78.

TOTAL H.P. 208.1

R.I. Loco. W'ks. 3/00 '90.

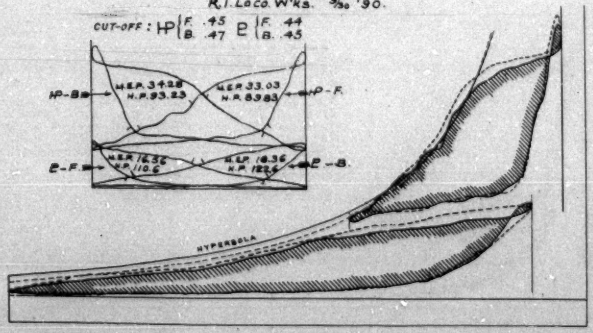

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PLATE VI

No. 3.

U.E.R.R. ENG. No. 58.

Steam 139½ Rev. 228.

Notch 2. Scale 80.

Av. M.E.P. { HP 40.80 / P 20.25 Ref to HP 49.61

TOTAL H.P. 173.

R.I. Loco. W'ks. 3/30 '90.

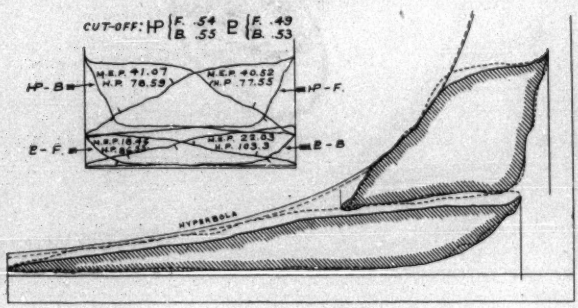

PLATE VII

No. 32.

U.E.R.R. ENG. No. 58.

Steam 161. Rev. 276.

Notch 2. Scale 80.

Av. M.E.P. { HP 47.78 / P 23.21 Ref to HP 56.86

TOTAL H.P. 242.4

R.I. Loco. W'ks. 3/30 '90.

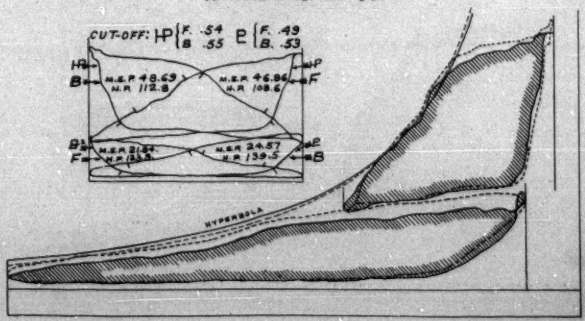

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PLATE VIII

No. 35.

U.E.R.R. ENG. No. 58.

Steam 157 Rev. 330.
Notch 2. Scale 80.

Av. M.E.P. { HP 42.07 / P 20.61 } REF. to HP 50.49.
TOTAL H.P. 256.5.

R.I. Loco. W'ks. 3/20 '90.

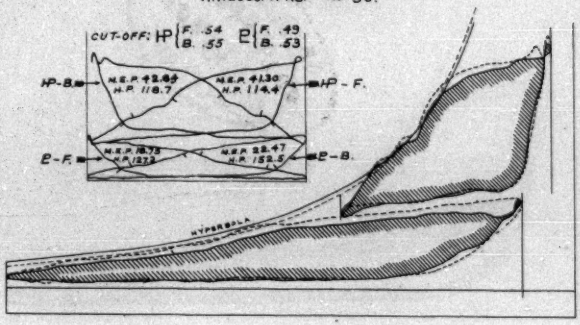

PLATE IX

No. 19.

U.E.R.R. ENG. No. 58.

Steam 161 Rev. 180
Notch 3. Scale 80.

Av. M.E.P. { HP 70.87 / P 29.49 } REF. to HP 72.25
TOTAL H.P. 216.3

R.I. Loco. W'ks. 3/20 '90.

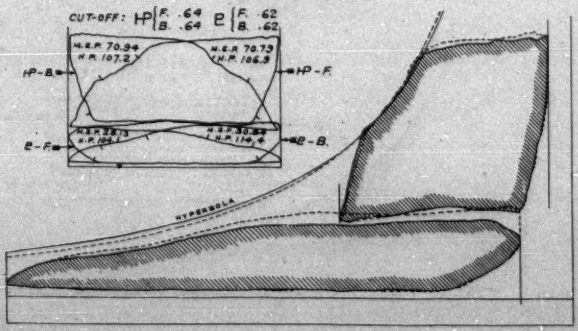

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PLATE X

No. 34.

U.E.R.R. ENG. No. 58.

Steam 748 Rev. 282
Notch 3. Scale 80.

Av. M.E.P. { HP 53.20 / P 25.60 REF to HP 62.72

TOTAL H.P. 274.4

R.I. Loco. W'ks. 3/90 '90.

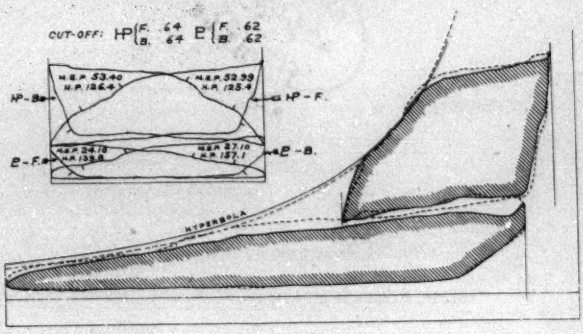

PLATE XI

No. 12.

U.E.R.R. ENG. No. 58.

Steam 748½ Rev. 306
Notch 3. Scale 80.

Av. M.E.P. { HP 49.70 / P 22.33 REF to HP 54.71

TOTAL H.P. 268.1

R.I. Loco. W'ks. 3/90 '90.

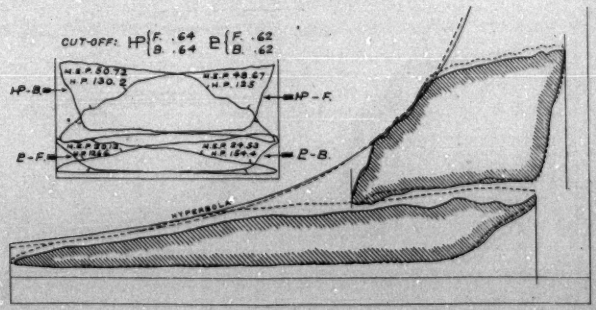

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PLATE XII

No. 15.

U.E.R.R. ENG. No. 58.

Steam 133½ Rev. 210

Notch 4 Scale 80

Av. M.E.P. { HP 61.01 / P 25.06 Ref. to HP 61.40

TOTAL H.P. 215.7

R.I. Loco. W'ks. 3/30 '90.

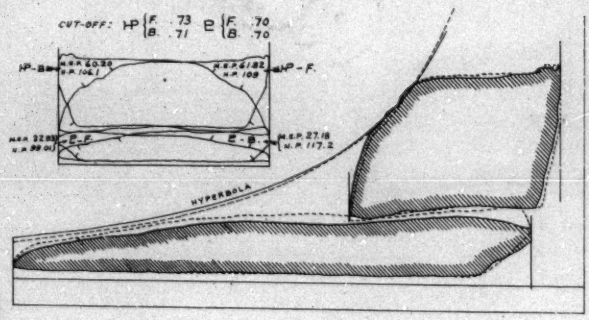

PLATE XIII

No. 44.

U.E.R.R. ENG. No. 58.

Steam 142½ Rev. 252.

Notch 4. Scale 80.

Av. M.E.P. { HP 61.51 / P 25.82 Ref. to HP 63.26

TOTAL H.P. 263.8.

R.I. Loco. W'ks. 3/30 '90.

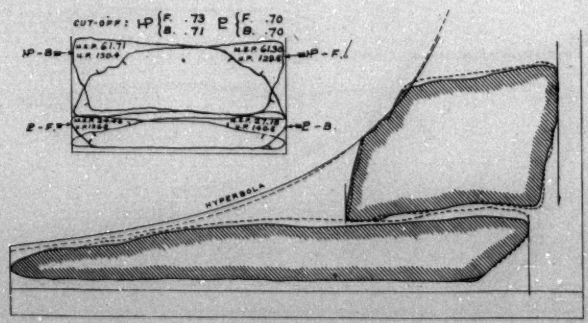

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PLATE XIV

No. 21.

U.E.R.R. ENG. No. 58.

Steam 153 Rev. 270

Notch 4. Scale 80.

Av. M.E.P. { HP 66.02 / P 27.50 } Ref. to HP 67.37.

TOTAL H.P. 302.3

R. I. Loco. W'ks. Dec '90.

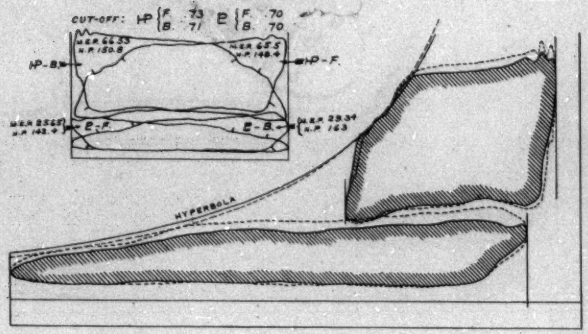

PLATE XV

No. 31.

U.E.R.R. ENG. No. 38.

Steam 145. Rev. 168.

Notch 5. Scale 80.

Av. M.E.P. { HP 74.01. / P 34.13. } Ref. to HP 83.64.

TOTAL H.P. 222.4.

R. I. Loco. W'ks. Dec '90.

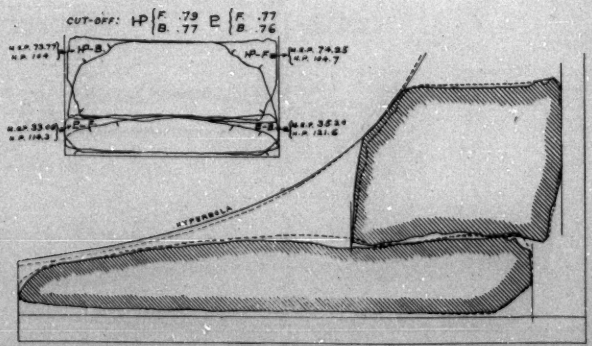

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PLATE XVI

No. 22.

U.E. R.R. ENG. No. 58.
Steam 156. Rev. 210.
Notch 5. Scale 80.
Av. M.E.P. { HP 78.40. / P 31.92. Ref. to HP 78.20.
TOTAL H.P. 276.
R.I. Loco. W'ks. '90.

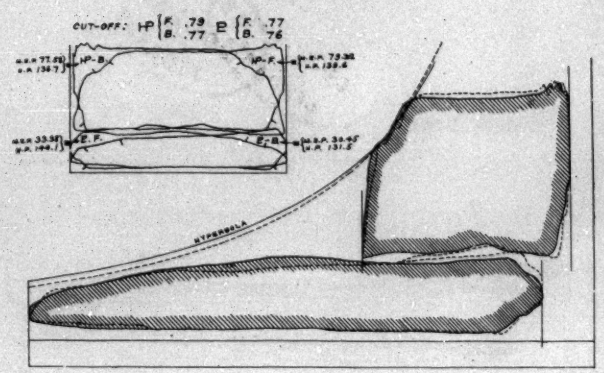

PLATE XVII

No. 1.

U.E. R.R. ENG. No. 58.
Steam 150. Rev. 100.
Notch 6. Scale 80.
Av. M.E.P. { HP 88.23 / P 33.45 Ref. to HP 81.95
TOTAL H.P. 192.84
R.I. Loco. W'ks. '90.

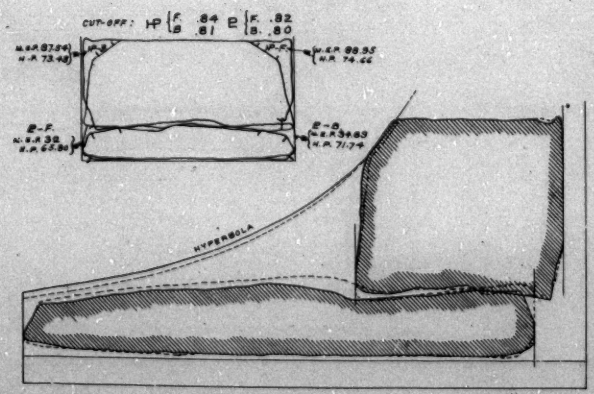

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PLATE XVIII

No. 17.

U.E. R.R. ENG. No. 88.

Steam 156. Rev. 192.

Notch 6. Scale 80.

Av. M.E.P. { HP 84.15. / P 33.59. Ref to HP 82.30.

TOTAL H.P. 266.6

R. I. Loco. W'ks. '90.

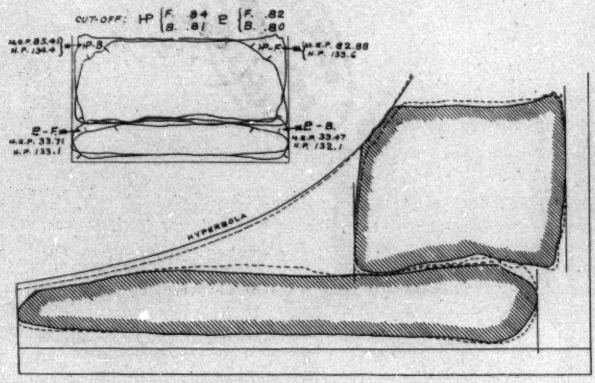


PLATE XIX

No. 32.

U.E. R.R. ENG. No. 88.

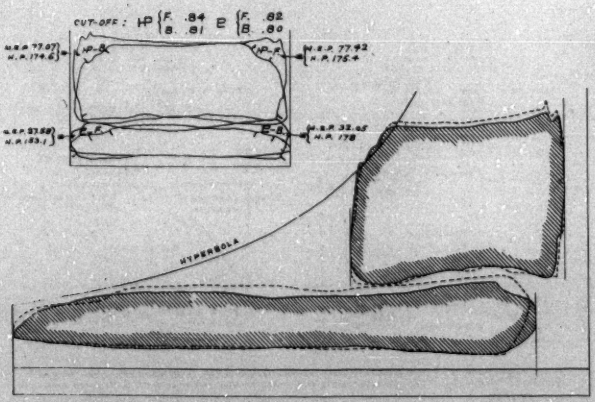
Steam 161. Rev. 270.

Notch 6. Scale 80.

Av. M.E.P. { HP 77.25 / P 29.82 Ref to HP 73.06

TOTAL H.P. 340.6

R. I. Loco. W'ks. '90.



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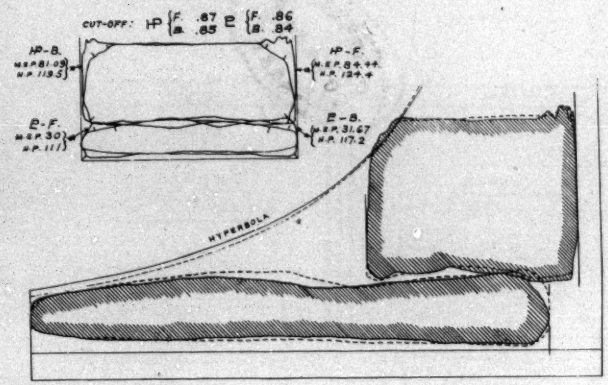
No. 27.

U.E. R.R. ENG. No. 58. PLATE XX

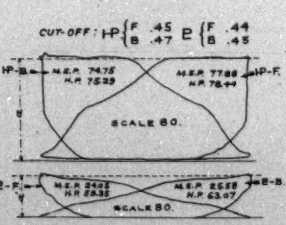
Steam 145. Rev. 180.
Notch 7. Scale 80.
Av. M.E.P. { HP 82.77 / E 30.84 } Ref. to HP 75.56.
TOTAL H.P. 236.1
R.I. Loco. Wks. 3/30 '90.



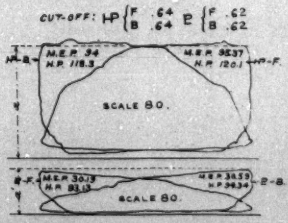
U. E. R.R. Eng. No. 58. PLATE XXI

DIAGRAMS IN SIMPLE SYSTEM.
R.I. Loco. Works.

No. 25 3/30
Speed 120 Rev.
Steam 128 Notch 1.
Av. M.E.P. { HP 76.31 / E 24.82 } Ref. to HP 60.81
TOTAL H.P. 139.08.



No. 42 3/30
Speed 150 Rev.
Steam 139½ Notch 3.
Av. M.E.P. { HP 94.69 / E 30.39 } Ref. to HP 74.45
TOTAL H.P. 212.9.



When HP piston has pressure & the E piston should have pressure a' to make each total piston pressure equal. The E cards show the wire-drawing of steam through the reducing valve at these speeds.

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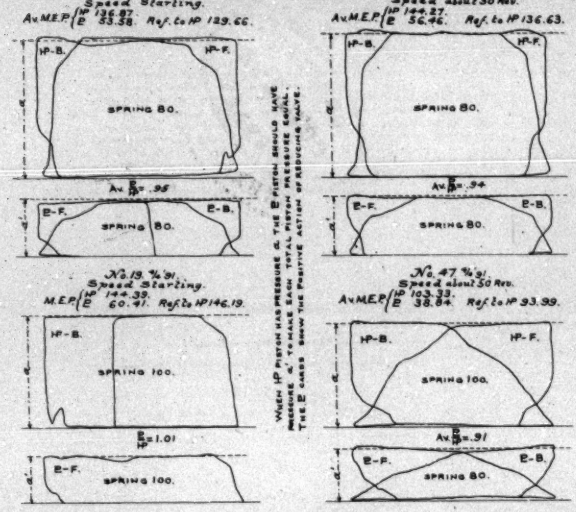
V.
18

Eng. No. 2600.
DIAGRAMS IN SIMPLE SYSTEM.
R.I. Loco. Works.



U.E.R.R. Eng. No. 58.
By
R.I. Loco. W'ks. ¾ '90.

Engine starts from rest at z, (both cards), both cylinders using direct steam to y (E card), one-half-revolution.

a is initial pressure in HP cylinder. a' is initial pressure which E cylinder should have, in order to make total pressures on both pistons equal.

x is the difference between pressure in receiver at time of changing into compound, and normal pressure in receiver when running compound, reverse lever remaining the same.

No. 20.
Steam 150. Notch 7. Scale 80.

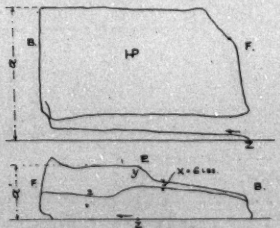


PLATE XXIII

No. 19.
Steam 148. Notch 7. Scale 80.

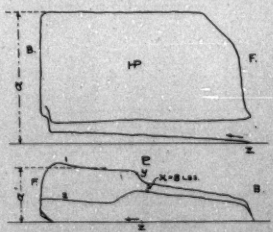


PLATE XXIV

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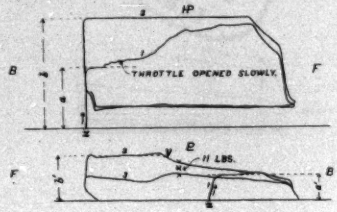
PLATE XXV

No. 14.
U.E.R.R. Eng. No. 58.
Steam 125. Notch 7. Scale 80.
R.I. Loco. W'ks. ⅜, '90.

Engine starts from rest at z, (both cards), both cylinders using direct steam to y, (E card), nearly one revolution.

a is first initial pressure in HP cylinder. a' is first initial pressure which E should have, in order to make total pressures on both pistons equal. b is third initial pressure in HP cylinder. b', (E card), is a pressure such that the ratio of b to b' is the same as the ratio of a to a'.

x is the difference between pressure in receiver at time of changing into compound and normal pressure in receiver when running compound, reverse lever remaining the same.



U.E.R.R. Eng. No. 58.
By
R.I. Loco. W'ks. ⅜, '90.

Engine starts from rest at z (both cards), both cylinders using direct steam, and changes into compound during exhaust stroke, (E card) not less than one revolution.

a is initial pressure in HP cylinder. a' is initial pressure which E cylinder should have in order to make total pressures on both pistons equal.

No. 15.
Steam 118. Notch 7. Scale 80.

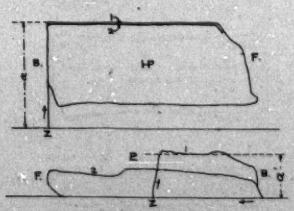


PLATE XXVI

No. 18.
Steam 145. Notch 7. Scale 80.

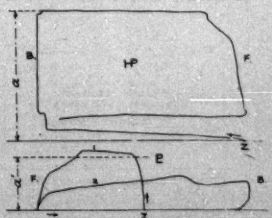


PLATE XXVII

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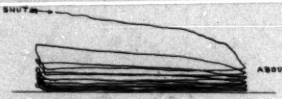
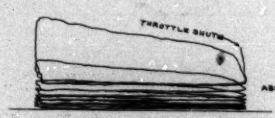
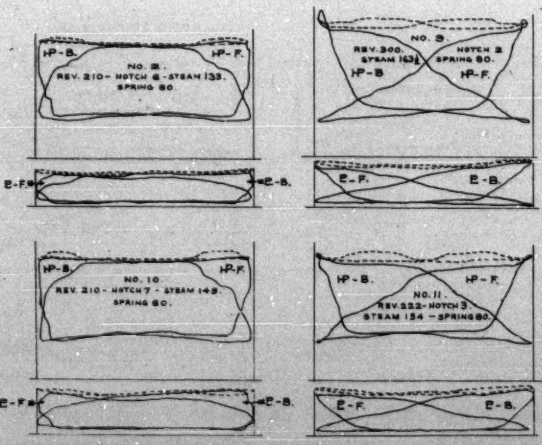

THROTTLE SHUT
ABOUT 8 REVOLUTIONS.


THROTTLE SHUT
ABOUT 8 REVOLUTIONS.


HP-B.
HP-F.
NO. 8.
REV. 210 - NOTCH 6 - STEAM 133.
SPRING 80.
E-F.
E-B.
NO. 9
REV. 300.
STEAM 163.
NOTCH 2.
SPRING 80.
HP-B
HP-F.
E-F.
E-B.
HP-B.
HP-F.
NO. 10.
REV. 210 - NOTCH 7 - STEAM 149.
SPRING 80.
E-F
E-B.
HP-B.
HP-F.
NO. 11.
REV. 232 - NOTCH 3.
STEAM 134 - SPRING 80.
E-F.
E-B.

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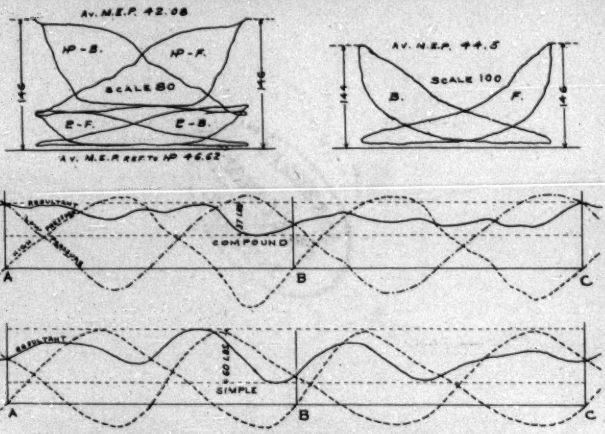
ROTATIVE EFFECTS. PLATE XXX

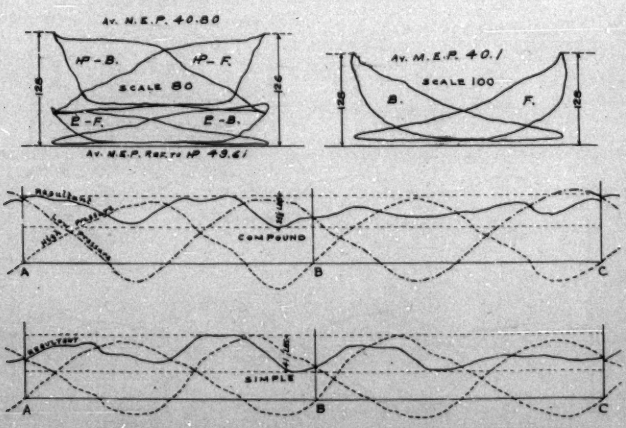
ON SIMPLE AND COMPOUND ENGINES FROM ACTUAL CARDS
OF SIMILAR INITIAL STEAM PRESSURES AND MEAN EFFECTIVE PRESSURES.



On each Diagram, straight line ABC is the development of Crank Pin Circle; scale, 2" = 1ft. A and C are at Back Dead Point of Left crank. B is at Forward Dead Point of Left crank. Heights above A B C represent ROTATIVE EFFECTS, 1" in height equalling 80 lbs. per sq in. of HP piston, exerted at Crank Pin at Right Angles to Crank.

ROTATIVE EFFECTS PLATE XXXI

ON SIMPLE AND COMPOUND ENGINES FROM ACTUAL CARDS
OF SIMILAR INITIAL STEAM PRESSURES AND MEAN EFFECTIVE PRESSURES.



On each Diagram, straight line ABC is the development of Crank Pin Circle; scale, 2" = 1ft. A and C are at Back Dead Point of Left crank. B is at Forward Dead Point of Left crank. Heights above A B C represent ROTATIVE EFFECTS, 1" in height equalling 80 lbs. per sq in. of HP piston, exerted at Crank Pin at Right Angles to Crank.

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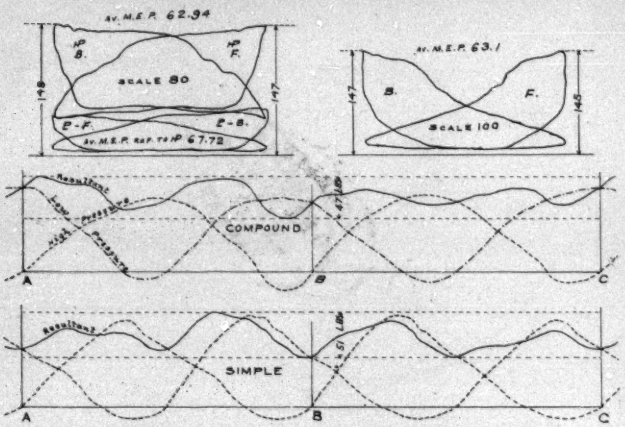
ROTATIVE EFFECTS. PLATE XXXII

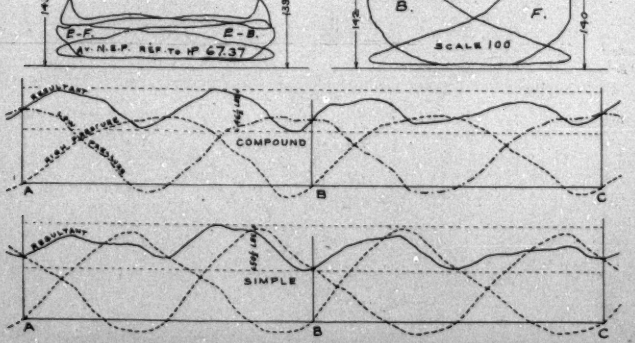
ON SIMPLE AND COMPOUND ENGINES FROM ACTUAL CARDS
OF SIMILAR INITIAL STEAM PRESSURES AND MEAN EFFECTIVE PRESSURES.



On each Diagram, straight line ABC is the development of Crank Pin Circle; scale, 2"=1ft. A and C are at Back Dead Point of Left crank. B is at Forward Dead Point of Left crank. Heights above ABC represent ROTATIVE EFFECTS, 1"in height equalling 80 lbs. per sq.in. of H.P piston, exerted at Crank Pin at Right Angles to Crank.

ROTATIVE EFFECTS PLATE XXXIII

ON SIMPLE AND COMPOUND ENGINES FROM ACTUAL CARDS
OF SIMILAR INITIAL STEAM PRESSURES AND MEAN EFFECTIVE PRESSURES.



On each Diagram, straight line ABC is the development of Crank Pin Circle; scale, 2"=1ft. A and C are at Back Dead Point of Left crank. B is at Forward Dead Point of Left crank. Heights above A B C represent ROTATIVE EFFECTS, 1"in height equalling 80 lbs. per sq.in. of H.P piston, exerted at Crank Pin at Right Angles to Crank.

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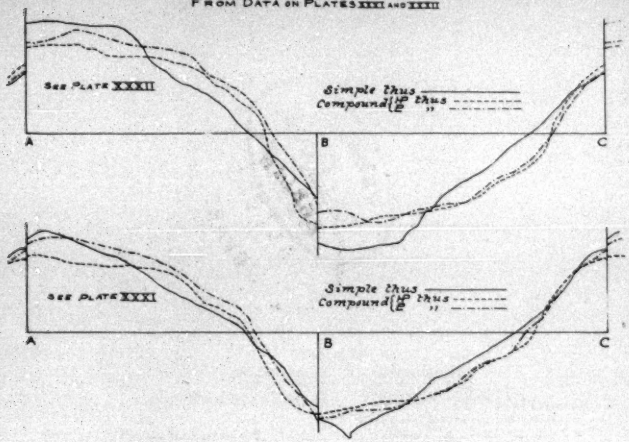
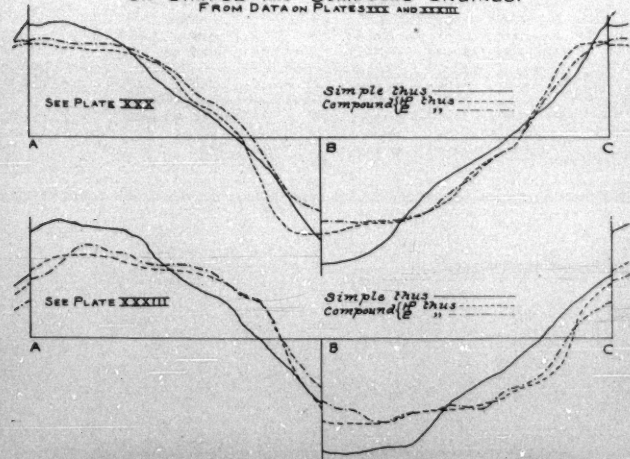
Crank-Pin Stress, Plate XXXIV
On Simple and Compound Engines.
From Data on Plates XXXI and XXXII



On each Diagram, straight line A B C is the development of crank pin circle; scale 2" = 1 ft. A and C are at the back dead point; B is at the forward dead point. Vertical distances from A B C represent total force acting on crank-pin, due to steam-pressure; 1 in height equalling 80 lbs. per sq. in. of HP piston. Distances above A B C correspond to pulls of the connecting-rod. Distances below A B C correspond to thrusts of the connecting-rod.

Crank-Pin Stress Plate XXXV
On Simple and Compound Engines.
From Data on Plates XXX and XXXIII



On each Diagram, straight line A B C is the development of crank pin circle; scale 2" = 1 ft. A and C are at the back dead point; B is at the forward dead point. Vertical distances from A B C represent total force acting on crank pin, due to steam-pressure; 1 in height equalling 80 lbs. per sq. in. of HP piston. Distances above A B C correspond to pulls of the connecting-rod. Distances below A B C correspond to thrusts of the connecting-rod.

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TABLE No. 4.

LOCOMOTIVE DIMENSIONS.

ENGINE	COMPOUND 2600	SIMPLE N.Y.P.&B. 34	SIMPLE P.R.R. 1738&136
FUEL	SOFT COAL	SOFT COAL	SOFT COAL
CYLINDER - SIZES - R.S.	26" × 24"	18" × 24"	18" × 22"
" " - L.S.	16" × 24"	18" × 24"	18" × 22"
DRIVERS - DIAMETER	78"	72"	70"
BOILER "	52"	52"	52"
" - FLUES - O.D.	2"	2"	2"
" " - NUMBER	214	200	221
" " - LENGTH	10'-10"	11'-10⅜"	11'-0"
GRATE - STYLE	CAST IRON ROCKING	CAST IRON ROCKING	CAST IRON ROCKING
" - SIZE	78⅛" × 34⅜"	72⅛" × 34⅜"	71⅛" × 35½"
" - AREA	18.65 SQ.FT.	17.72 SQ.FT.	17.41 SQ.FT.
HEATING SURFACE - TOTAL	1243.83 "	1236.63 "	1236.62 "
" " - FIRE BOX	157.57 " (INCLUDING 19.83 SQ.FT. FIRE BRICK TUBES)	120.95 "	116.78 "
" " - FLUES	1086.26 "	1115.68 "	1119.84 "
AREA RATIO - HEATING SURFACE TO GRATE	66.69	69.78	71.02
WEIGHTS - LOADED	105250 LBS.	91250 LBS.	91000 LBS.
" " - DRIVERS	66520 "	60200 "	61500 "
" " - TRUCK	34710 "	31050 "	29500 "

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TABLE Nº 5-A

GENERAL DATA AND RESULTS OF TESTS ON NEW YORK, PROVIDENCE AND BOSTON R. R.

SCHEDULE RUNNING TIME - TRAIN Nº. 23. PROVIDENCE TO NEW LONDON - 64 MLS. - 1HR. 40 MINS.

SCHEDULE RUNNING TIME - TRAIN Nº 42. NEW LONDON TO PROVIDENCE - 1HR. 41 MINS.

ENGINE.	DATE-1891	TRAIN Nº. 23-WEST. RUNNING TIME PROV. TO N. LONDON	AVERAGE SPEED IN MILES PER HOUR	CAR MILEAGE	TRAIN WEIGHT EMPTY - TONS	REMARKS	TRAIN Nº. 42-EAST. RUNNING TIME N. LONDON TO PROV.	AVERAGE SPEED IN MILES PER HOUR	CAR MILEAGE	TRAIN WEIGHT EMPTY - TONS	REMARKS	COAL WEIGHED OUT TO ENGINE. POUNDS.
NYP&B-34	9/16	1:47	35.95	448		HOT BOX TRAIN LEFT 8 MINS. LATE						
	9/17	1:24	43.24	448		" " 17 " "	1:41	38.06	512		DELAYED BY TRAIN Nº. 185 TRAIN LEFT 18 MINS. LATE	8617
	9/18	1:40	38.55	448		" " ON TIME	1:36	40.0	448		DELAYED BY TRAIN Nº. 184 TRAIN LEFT 6 MINS. LATE	9033
				TOTAL 344	TOTAL				TOTAL 1408	TOTAL	WEIGHED BACK	9022
											TOTAL APPT. COAL BURNED DURING TEST	2134
COMPOUND-2600	9/19	1:40	38.55	448		TRAIN LEFT ON TIME	1:35	40.5	448			6482
	9/20	1:40	38.55	448		" " " "	1:42	37.64	448			8236
	9/21	1:34	36.78	448		" " 1 MIN. LATE	1:35	33.8	512			4418
				TOTAL 1344	TOTAL				TOTAL 1408	TOTAL	WEIGHED BACK	3000
											TOTAL APPT. COAL BURNED DURING TEST	5336

Nº. OF REGULAR STOPS TRAIN Nº. 23-3

REGULAR SLOWNESS AT TIME OF TESTS:- ELIZABETH-ON ACCT. OF EXCAVATIONS. MYSTIC BRIDGE. NEW LONDON BRIDGE

Nº. OF REGULAR STOPS TRAIN Nº. 42-3

TABLE Nº. 5-B

SUMMARY

ENGINE NUMBER	TOTAL CAR MILEAGE	TOTAL COAL CONSUMPTION	AVERAGE AMOUNT OF COAL USED PER CAR MILE	PERCENTAGE OF COAL SAVED	AVERAGE RUNNING TIME PROV. TO N. LON.	AVERAGE RUNNING TIME N. LON. TO PROV.	AVERAGE MILES PER HOUR PROV. TO N. LON.	AVERAGE MILES PER HOUR N. LON. TO PROV.
34	2752	12.27 TONS	8.91 LBS.	———	1HR. 38.6 MINS.	1HR. 34 MINS.	34.25	38.88
2600	2752	9.17 "	6.66 "	25.2 %	1 - 39.6 "	1 - 44 -	38.63	37.21

TABLE Nº 6-A

GENERAL DATA AND RESULTS OF TESTS ON NEW YORK, PROVIDENCE AND BOSTON R. R.

SCHEDULE RUNNING TIME - TRAIN Nº 39. PROVIDENCE TO NEW LONDON - 64 MLS. - 1HR. 35 MINS.

SCHEDULE RUNNING TIME - TRAIN Nº 50. NEW LONDON TO PROVIDENCE. - 1HR. 35 MINS.

ENGINE	DATE-1891	TRAIN Nº. 39-WEST. RUNNING TIME PROV. TO N. LONDON	AVERAGE SPEED IN MILES PER HOUR	CAR MILEAGE	TRAIN WEIGHT EMPTY - TONS	REMARKS	TRAIN Nº. 50-EAST. RUNNING TIME N. LONDON TO PROV.	AVERAGE SPEED IN MILES PER HOUR	CAR MILEAGE	TRAIN WEIGHT EMPTY - TONS	REMARKS	COAL WEIGHED OUT TO ENGINE. POUNDS.
N.Y.P.&B.-34	9/14	1:24	43.38	384		9 SLOW-UPS	1:25	45.77	384		4 SLOW-UPS	8316
	9/15	1:32	42.40	384		2 SLOW-UPS & 1 STOP AT DRAW AT WHICH TO CLEAN FIRE. TIME ALLOWED FOR STOP 4 MINS. 1 MIN. LATE	1:30	43.10	384		2 SLOW-UPS & EXTRA STATION STOPS	7123
	9/16	1:30	43.10	384		3 SLOW-UPS	1:28	44.06	384		4 SLOW-UPS	4780
	9/16	1:28	44.06	384		4 " "	1:27	44.82	384		3 " "	4796
	9/16	1:32	42.20	384		4 " "	1:29	43.83	384		2 " "	4478
	9/17	1:33	41.72	384		5 " "	1:23	46.76	384		1 SLOW-UP & EXTRA STOP AWAY FOR BANKER & SWITCH ENGINE	3945
				TOTAL 2304	TOTAL				TOTAL 2304	TOTAL	WEIGHED BACK	1932
											TOTAL APPT. COAL BURNED DURING TESTS	31806
COMPOUND-2600	9/14	1:26	46.30	384		2 SLOW-UPS	1:26	45.36	384		2 SLOW-UPS	7750
	9/15	1:33	41.93	384		1. SLOW-UP & TUNNEL SPOT AT TIMES TO HAVE ENGINE ARRANGED, THEN BANKED.	1:26	45.18	384		2 " "	3510
	9/16	1:24	43.58	384		2. SLOW-UPS & TUNNEL SPOT AT TIMES TO CLEAN UP ENGINE, THEN BANKED.	1:26	45.13	384		2 " "	4655
	9/16	1:32	42.20	384		3 SLOW-UPS	1:30	43.33	384		2 " "	4338
	9/16	1:30	43.10	384		3 " "	1:31	42.87	384		2 " "	4618
	9/17	1:32	42.07	384		4 " "	1:22	47.27	384		2 " "	3774
				TOTAL 2304	TOTAL				TOTAL 2304	TOTAL	WEIGHED BACK	1667
											TOTAL APPT. COAL BURNED DURING TESTS	27143

Nº. OF REGULAR STOPS TRAIN Nº. 39-1.

Nº. OF REGULAR STOPS TRAIN Nº. 50-1

TABLE Nº. 6-B

SUMMARY

ENGINE NUMBER	TOTAL CAR MILEAGE	TOTAL COAL CONSUMPTION	AVERAGE AMOUNT OF COAL USED PER CAR MILE	PERCENTAGE OF COAL SAVED	AVERAGE RUNNING TIME PROV. TO N. LOND.	AVERAGE RUNNING TIME N. LOND. TO PROV.	AVERAGE MILES PER HOUR PROV. TO N. LOND.	AVERAGE MILES PER HOUR N. LOND. TO PROV.
34	4608	13.9 TONS	6.9 LBS.	———	1HR. 31 MINS.	1HR. 27.3 MINS.	42.54	44.72
2600	4608	13.59 "	5.9 "	14.52 %	1 - 30.7 "	1 - 27 "	43.04	44.84

	ENGINE NUMBER	EVAPORATED IN BOILER	USED IN CYLINDERS	POUNDS EVAPORATED PER POUND OF COAL	PERCENTAGE WATER DRIVEN USED IN CYLINDERS
WATER ACCOUNT	34	25140 GALLONS	25087 GALLONS	6.56 LBS. FROM 43.5°	
	2600	23612 "	23706 "	7.90 - " 33.25°	55 %

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TABLE Nº 7-A
GENERAL DATA AND RESULTS OF TESTS
ON BOSTON AND ALBANY R.R.

SCHEDULE RUNNING TIME - TRAIN Nº. 19
BOSTON TO WORCESTER — 44 miles — 68 MINS.
WORCESTER TO CHARLTON — 13.9 " — 24 "
CHARLTON TO SPRINGFIELD — 41 " — 43 "
BOSTON TO SPRINGFIELD — 98.9 " — 2 HRS. 25 MINS.

SCHEDULE RUNNING TIME - TRAIN Nº. 18
SPRINGFIELD TO CHARLTON — 39 MINS.
CHARLTON TO WORCESTER — 23 "
WORCESTER TO BOSTON — 70 "
SPRINGFIELD TO BOSTON — 2 HRS. 12 MINS.

ENGINE	DATE - 1891	TRAIN Nº. 19 - WEST: RUNNING-TIME IN MINUTES: BOSTON TO WORCESTER	WORCESTER TO CHARLTON	CHARLTON TO SPRINGFIELD	BOSTON TO SPRINGFIELD	AVERAGE SPEED IN MILES PER HOUR: BOSTON TO WORCESTER	WORCESTER TO CHARLTON	CHARLTON TO SPRINGFIELD	BOSTON TO SPRINGFIELD	CAR MILEAGE	TRAIN WEIGHT EMPTY - TONS	CAUSES OF DELAY	TRAIN Nº. 18 - EAST: RUNNING-TIME IN MINUTES: BOSTON TO WORCESTER	WORCESTER TO CHARLTON	CHARLTON TO SPRINGFIELD	BOSTON TO SPRINGFIELD	AVERAGE SPEED IN MILES PER HOUR: SPRINGFIELD TO CHARLTON	CHARLTON TO WORCESTER	WORCESTER TO BOSTON	SPRINGFIELD TO BOSTON	CAR MILEAGE	TRAIN WEIGHT EMPTY - TONS	CAUSES OF DELAY	COAL CONSUMPTION POUNDS PER TON-MILE
COMPOUND-2600	7/5	71	23	60	2:34	37.88	44.92	39.4				FREIGHT AT SO. FRAMINGHAM	68	23	64	2:41	36.71	39.1	41	182.9	HOT BOX ON CAR NEAR BOSTON.	3.5
	7/6	69	23	64	2:36	37.88	39.4	41	131				71	23	64	2:43	36.26	39.1	41	182.9	SWITCH-ENG. AT BOSTON	3.3
	7/8	69	24	63	2:36	37.88	39.4	41	131				74	23	68	2:45	35.81	39.1	40.6	182.9		3.5
	7/9	71	24	61	2:36	37.88	39.4	38	141.8	SIGNALS & SLOW-UP NEAR KINGS & SLOW-UP AT SO. FRAMINGHAM			73	23	70	2:46	35.68	39.1	42.5	184.9		3.5
	7/11	71	25	70	2:46	35.68	39.4	38	131	SWITCHMAN TO STOP EXCURSION TRAIN AHEAD OF US NEAR SPRINGFIELD			69	24	68	2:41	36.71	39.1	42.5	184.9	WORCESTER JC. SIGNAL AT TOWER S	3
	7/12	69	25	66	2:36	37.88	39.4	38	131	FREIGHT NEAR CHARLTON			70	23	65	2:38	37.45	39.1	42.5	184.9		3.5
	7/14	72	23	62	2:37	37.54	39.4	38	131	FREIGHT AT WORCESTER			72	23	69	2:44	36.08	39.1	42.5	184.9		3
	7/20	71	23	60	2:36	37.88	39.4	38	131	SLOW-UP AT WARRESTER			73	23	70	2:46	35.68	39.1	42.5	184.9		2.5
	7/21	72	24	62	2:40	37.03	39.4	42.5	138.4	SIGNAL AT WORCESTER & DISTANCE AT CHARLTON			72	23	67	2:42	36.46	39.1	42.5	184.9		3
B. & A-136	8/24	70	24	63	2:39	37.17	39.4	38	131	WAIT FOR ORDERS AT WARCES. & CHARLTON			73	23	65	2:41	36.71	39.1	41	182.9		4
	8/28	70	23	64	2:39	37.88	39.4	38	131	WAIT FOR ORDERS AT WORCESTER			72	23	64	2:44	36.08	39.1	42.5	184.9		5
	8/29	70	27	64	2:38	37.88	39.4	38	131	SLOW-UPS AT WARCES.			69	23	65	2:37	37.54	39.1	41	182.9		4
	8/31	72	25	61	2:38	37.45	39.4	42.5	138.4	WAIT PER ORDERS AT WORCESTER			71	23	70	2:44	36.08	39.1	42.5	184.9		5.5
	9/4	72	22	63	2:37	37.54	39.4	38	131	SIGNALS AT WORCESTER			74	23	70	2:47	35.48	39.1	42.5	184.9		4
	9/5	70	24	62	2:36	37.88	39.4	38	131	SLOW-UP AT WORCESTER			71	23	70	2:44	36.08	39.1	42.5	184.9		4.5
	9/6	69	22	63	2:34	38.41	39.4	38	131				73	23	70	2:46	35.68	39.1	42.5	184.9		3.5
	9/7	70	23	64	2:37	37.54	39.4	38	131	WAIT FOR ORDERS AT WORCESTER			74	23	67	2:44	36.08	39.1	42.5	184.9		4
	9/8	69	23	64	2:36	37.88	39.4	38	131				72	23	69	2:44	36.08	39.1	42.5	184.9		5

Nº. OF REGULAR STOPS TRAIN 19 - 1. Nº. OF REGULAR STOPS TRAIN 18 - 2.

TABLE Nº. 7-B
SUMMARY

ENGINE NUMBER	TOTAL CAR MILEAGE	TOTAL COAL CONSUMPTION	AVERAGE AMT. OF COAL USED PER CAR MILE	PERCENTAGE OF COAL SAVED	AVERAGE RUNNING TIME: BOS. TO SPRING.	SPRING. TO BOS.	AVERAGE MILES PER HOUR: BOS. TO SPRING.	SPRING. TO BOS.
2600	8613.0	29 TONS	6.73 LBS.	28.63 %	2 HRS. 37½ MINS.	2 HRS. 39½ MINS.	37.51	36.32
136	8372.5	34.5 "	9.43 LBS.	——	2 " 36½ "	2 " 43½ "	37.75	36.2

TABLE Nº. 8-A
GENERAL DATA AND RESULTS OF TESTS
ON BOSTON AND ALBANY R. R.

SCHEDULE RUNNING TIME - TRAIN Nº. 83
BOSTON TO WORCESTER — 44 miles — 70 MINS.
WORCESTER TO CHARLTON — 13.9 " — 24 "
CHARLTON TO SPRINGFIELD — 41 " — 44 "
BOSTON TO SPRINGFIELD — 98.9 " — 2 HRS. 14 MINS.

SCHEDULE RUNNING TIME - TRAIN Nº. 50
SPRINGFIELD TO CHARLTON — 39 MINS.
CHARLTON TO WORCESTER — 22 "
WORCESTER TO BOSTON — 69 "
SPRINGFIELD TO BOSTON — 2 HRS. 10 MINS.

ENGINE	DATE - 1891	TRAIN Nº. 83 - WEST: RUNNING-TIME IN MINUTES: BOSTON TO WORCESTER	WORCESTER TO CHARLTON	CHARLTON TO SPRINGFIELD	BOSTON TO SPRINGFIELD	AVERAGE SPEED IN MILES PER HOUR: BOSTON TO WORCESTER	WORCESTER TO CHARLTON	CHARLTON TO SPRINGFIELD	BOSTON TO SPRINGFIELD	CAR MILEAGE	TRAIN WEIGHT EMPTY - TONS	CAUSES OF DELAY	TRAIN Nº. 50 - EAST: RUNNING-TIME IN MINUTES: SPRINGFIELD TO BOSTON	SPRINGFIELD TO CHARLTON	CHARLTON TO WORCESTER	WORCESTER TO BOSTON	AVERAGE SPEED IN MILES PER HOUR: SPRINGFIELD TO CHARLTON	CHARLTON TO WORCESTER	WORCESTER TO BOSTON	SPRINGFIELD TO BOSTON	CAR MILEAGE	TRAIN WEIGHT EMPTY - TONS	CAUSES OF DELAY	COAL CONSUMPTION POUNDS PER TON-MILE
COMPOUND-2600	7/17	77	24	57	2:38	37.45	39.4	35	140.8	SWITCHBACK TO OTHER MAIN AT SO. FRAM.			73	21	65	2:34	37.17	36.2	41.2	181.9		4
	7/19	70	23	65	2:38	37.45	39.4	41	180	SWITCHBACK TO OTHER MAIN AT SPRINGFIELD			70	22	67	2:36	37.17	36.2	41.2	181.9		3.5
	7/16	70	25	62	2:37	37.54	39.4	41	180				69	22	68	2:36	37.17	36.2	41.2	181.9		3
	7/17	75	23	59	2:37	37.54	39.4	41	180	SLOW-UP BET. SO. FRAM. & WORCESTER			72	22	64	2:36	37.45	36.2	41.2	181.9		3
	7/18	71	24	62	2:37	37.54	39.4	41	180				70	22	64	2:36	37.88	37.05	41.2	181.9		3
	7/20	70	25	62	2:37	37.54	39.4	41	180				72	22	69	2:43	34.86	36.2	41.2	181.9		3.5
	7/21	73	24	61	2:38	37.45	39.4	41	180				71	22	66	2:39	37.17	36.2	41.2	181.9		4
B & A-173	7/6	71	24	61	2:38	37.45	39.4	39.5	207.4	TRACK OF W. DIVERGES AT FRAM. FROM ANOTHER MAIN OF W.			70	22	70	2:42	34.86	36.2	40.9	243.2		5
	7/14	71	25	61	2:37	37.54	39.4	41	180				69	23	67	2:36	37.45	36.2	41.2	181.9		4.5
	7/15	70	24	64	2:38	37.45	39.4	41	180				70	22	67	2:36	37.17	36.2	41.2	181.9		4
	7/19	70	24	64	2:38	37.45	39.4	41	180				71	20	65	2:36	37.88	36.2	41.2	181.9		4
	7/10	73	24	61	2:38	37.45	39.4	41	180				69	22	65	2:36	37.88	36.2	41.2	181.9		4
	7/11	72	23	61	2:36	37.88	39.4	41	180				69	22	67	2:38	37.45	36.2	41.2	181.9		4.5
	7/13	72	23	61	2:36	37.88	39.4	41	180				69	22	67	2:38	37.45	36.2	41.2	181.9		4.5

Nº. OF REGULAR STOPS TRAIN 83 - 1. Nº. OF REGULAR STOPS TRAIN 50 - 4.

TABLE Nº. 8-B
SUMMARY

ENGINE NUMBER	TOTAL CAR MILEAGE	TOTAL COAL CONSUMPTION	AVERAGE AMT. OF COAL USED PER CAR MILE	PERCENTAGE OF COAL SAVED	AVERAGE RUNNING TIME: BOS. TO SPRING.	SPRING. TO BOS.	AVERAGE MILES PER HOUR: BOS. TO SPRING.	SPRING. TO BOS.
2600	8860	23.5 TONS	5.48 LBS.	21.6 %	2 HRS. 37.4 MINS.	2 HRS. 39 MINS.	37.53	37.18
173	8718	30.5 "	8.49 "	——	2 - 37½ -	2 - 38 -	37.59	37.39

Diagram of Intercepting Valve — by R.I. Locomotive Works.

Patented Sept. 22. 91.

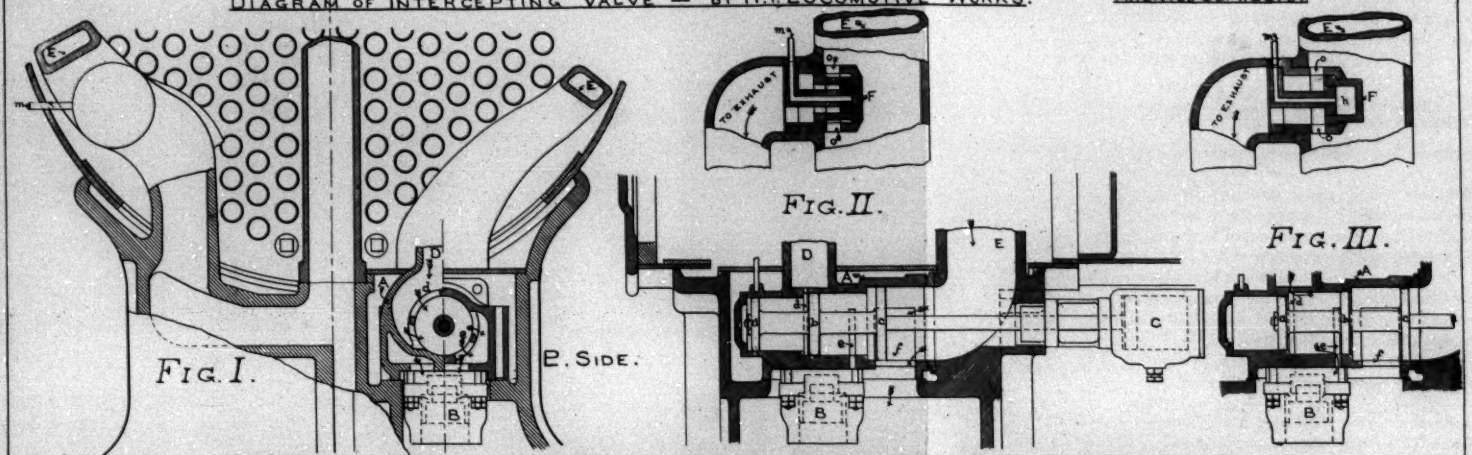


Fig. I shows front section of intercepting valve at ports d and e, also front view of portion of receiver with exhaust valve.

Fig. II shows side section of same while running compound. Fig. III shows same while running simple.

A (in fig's I-II-III) intercepting valve casing. – B (in fig's I-II-III) reducing valve. – C (in fig. II) oil dash pot. – D (in fig's I-II) pipe from main steam pipe to intercepting valve. – E (in fig's I-II-III) the receiver. – F (in fig's II-III) exhaust valve.

a-b-c (in fig's II-III) intercepting valve piston. d (in fig's I-II-III) port from D through A. e (in fig's I-II-III) port from A into the reducing valve B. f (in fig's II-III) port from A into passage to E steam chest.

m (in fig's I-II-III) small pipe and passage connecting hand valve in cab to chamber h. o (in fig's II-III) port through exhaust valve casing.

The device shown above operates as follows:

The intercepting valve being in any position as in fig. II, and the exhaust valve closed as in fig. II, the throttle being opened; boiler steam will pass to the H.P. cylinder in the usual manner, and also through pipe D into the intercepting valve A, causing the piston to move into the position shown in fig. III. In this position the receiver is closed to the L.P. cylinder by the piston C, and steam from D passes through ports d and e, and reducing valve B, into the L.P. steam chest; the pressure being reduced from boiler pressure in the ratio of the cylinder areas. The piston a-b-c, is so proportioned that it will automatically change to the compound position shown in fig. II, when a predetermined pressure in the receiver E has been reached by exhausts from the H.P. cylinder. The engine thus starts with steam in both cylinders, and automatically changes to compound at a desired receiver pressure.

The engine may be changed from the compound system to the simple at any time, at the will of the engineer, by opening the valve F connecting the receiver to the exhaust pipe, allowing the exhausts from the H.P. cylinder to escape through the nozzle in the usual manner.

The exhaust valve F is operated as follows:—the small pipe m is from a hand valve in cab connecting it to either steam or atmosphere. When desiring to run compound, m is in connection with atmosphere, the receiver steam keeping valve F in position as per fig. II. To run simple m is connected to steam which will hold the valve F as in fig. III, the ports o opening E to the exhaust. The valve F takes either position at any time at the will of the engineer.

It is obvious that, in case of bad conditions of starting, the engine may be operated as a simple one at the will of the engineer by opening the exhaust valve before starting, and that upon its closure the piston a-b-c will automatically take the compound position of fig. II, as described in the first paragraph.

APPENDIX II.

(*A*) CONTAINING THE DATA AND DESCRIPTIVE MATTER RELATING TO EXISTING INVENTIONS AND MECHANISMS, DEVISED BY OTHERS FOR OPERATING TWO CYLINDER COMPOUNDS—PUBLISHED AT HOME AND ABROAD—TOGETHER WITH THE EXPERIENCE AND OPINIONS OF THE MEMBERS OF THE COMMITTEE ON COÖRDINATE BRANCHES OF THE SUBJECT.

"The locomotive is not the invention of one man, but of a nation of mechanical engineers."
—ROBERT STEPHENSON.

The pen of locomotive history has recorded little or nothing of practical value during the first twelve centuries of our era.

Whether the announcement of M. Pambour, made in the year 1835, that "locomotive engines were the first of all engines," be true or not, we can refer with confidence to the words of Roger Bacon, written more than 600 years ago, in which he says: "We will be able to propel carriages with incredible speed without the assistance of any animal."

The long years succeeding this prophecy were filled with "speculations wild and visionary theories absurd" (so the records tell us), down to the date of Ramsay's English patent in 1618, which, in the quaint language of the time, offers us: "*A farre more easie and better waye for the carrying of coaches, carts, drayes and other things, going on wheels, than ever yet was used or discovered.*"

Even the great Sir Isaac Newton, in the year 1680, tries his hand at inventing a road locomotive, but whether it ever passed beyond "the idea only for other minds to work upon," history is silent.

The period of fruitful experiment with locomotive engines having cylinders and pistons and the necessary valve gear with linkages to cranks, begins with a French engineer, named Cugnot, in the years 1763 to 1770, and was continued by Murdock in 1784, and by Trevithick and Vivian in 1800, who at once solved the problems of high-pressure steam and simplicity of construction. Our "Watt of America"—Oliver Evans—in 1804, built that odd machine which was at home on land or in water, and, in common with Murdock, used the "grasshopper engine," with vertical steam cylinder.

Gurney's steam coach of 1828 is interesting as showing a horizontal cylinder having rod connections from a piston to a cranked driving-wheel axle, upon which is an eccentric for working the valve, arranged for cutting off at half stroke and with a link for reversing. He also used one of the earliest "sectional boilers," in which he carried steam of seventy pounds pressure per square inch.

But when the celebrated Rainhill trial came off in October 6, 1829, Stephenson's "Rocket" held the track alone, having more than performed all the stipulated conditions. This was the result of Stephenson's resolve in 1813 to make himself thoroughly acquainted with what had already

been done, and of subsequent application to accomplish the grand object of inventing an efficient and economical working locomotive.

Much of this history was, of course, interlined with inventions, which, like pure intents, came to nothing; many were worthily conceived, but were bad in construction, and for want of proper tools and ripeness of time were never repeated.

Stephenson's "Rocket" achieved a great victory, impressing the assembled multitude, on the occasion of the great trial, as well as the people throughout the whole kingdom. It ushered in a widespread railway mania, taking precedence over every other enterprise.

"Nothing will beat the locomotive," says Stephenson, "for efficiency in all weathers, for economy in drawing loads and for power and speed as occasion may require." We need not ask as to the fulfilment of Stephenson's prediction. It is everywhere, in every country, amply verified.

The locomotive, with two equally sized high-pressure cylinders, improved and perfected from the Stephenson model, which "held the road" in his day, is well nigh the universal type of our time.

Let us right here be particular in our statements regarding the earliest conception and development of the two-cylinder compound steam engine. There have been many opinions published concerning the origin of this important invention. We make no further apology, therefore, for setting this matter aright, and quote Mr. Wm. Pole's conclusions from his thorough study and publication of them in *Newton's London Journal of Arts*, for August, 1863:

"The double-cylinder engine was invented by Jonathan Hornblower, a mechanical engineer of considerable eminence in Cornwall, who took an important part in the application of the steam engine in that district, during the early part of Watt's career. The idea appears to have occurred to him early in the year 1776, if not before.

"He experimented upon a large working model. The cylinders of which were eleven and fourteen inches diameter, respectively; and he published his invention in 1781, describing it as consisting in the employment of two steam cylinders—the steam after it had acted in the first cylinder being employed a second time in the other, by permitting it to expand itself; the two cylinders being connected together by suitable steam ports and valves. At the same time, he described also, shortly but clearly, several other inventions relating to the steam engine. One referring to surface condensing, which is so much applied in modern days; others to means of getting rid of the air and condensing water; and another invention was a steam piston, which altered into a steam stuffing-box, is in common use at the present time. Here, therefore, was clearly developed the theoretical principle as well as the practical application of the expansion of steam; and it is beyond dispute that the first publication of the principle to the world was this of Hornblower's."

Dr. Thurston, in his *Growth of the Steam Engine*, says: "Richard Trevithick was the first engineer to apply steam power to the haulage of loads on the railroad."

Mr. Samuel Smiles, in his *Lives of the Stephensons*, recorded the following important departure from almost universal previous practice: "In Trevithick's engine, the piston was not only raised, but was depressed by the action of the steam, being in this respect an entirely original invention and of great value."

"Mr. Trevithick knew of Mr. Hornblower's double-cylinder engine in the year 1792; he had spoken to Davies Gilbert in 1796 on the possibility of making an engine to work by the force of steam."

"An old account book of Trevithick's, dated 1800, gives the detail items in the manufacture of the first steam carriage." "It was in progress in 1800, and on Christmas-eve, 1801, conveyed the first load of passengers ever moved by the force of the steam."

"Trevithick's high-pressure engine, which was worked by the force of steam, sixty pounds or more to the square inch.

"One of the gains from the Trevithick's high-pressure engine was its portability and cheapness.

"This engine had little or no resemblance to any steam engine that had preceded it.

"The boiler was cylindrical, in which the steam cylinder was fixed; the tubular boiler flues were of wrought iron, and entirely within the boiler.

"The exhausted steam having done its work in the cylinder, at a pressure of sixty pounds to the inch, passed into the chimney as a steam blast, causing an intensely hot fire, and in its passage heated the feed water.

"A patent was granted on the 24th of March, 1802, to Richard Trevithick and Andrew Vivian, for steam engines for propelling carriages, etc., which may be read and studied by the young engineer with pleasure and profit, even in this age of greatly-improved steam mechanism."

Mr. Trevithick, in the year 1802, made engines having two steam cylinders, which were connected to cranks at right angles, and they used the "blast-pipe;" such engines were called "puffers."

These engines were the first of the high-pressure double-cylinder type used in Cornwall. Mr. Trevithick's patent of 1802 recommends the use of two cylinders.

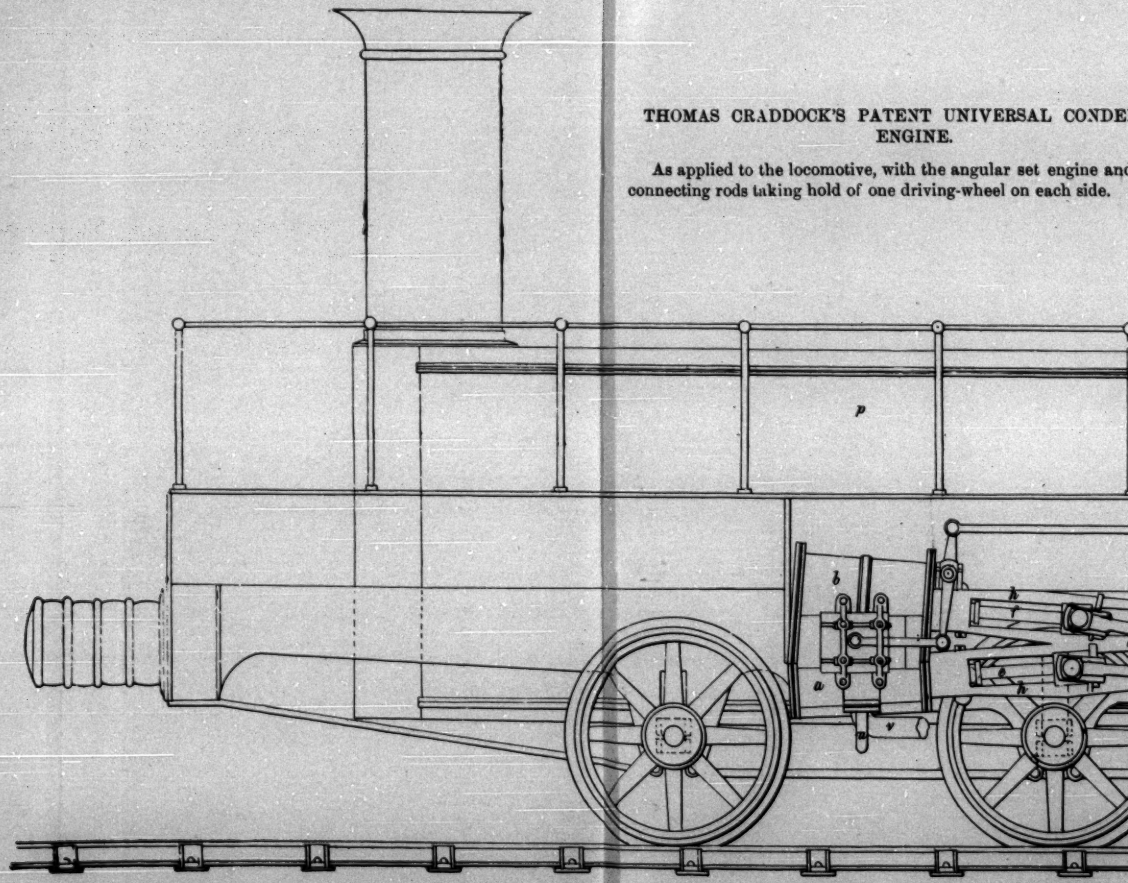
"The specification of the patent granted to Messrs. Trevithick and Vivian is descriptive of a high-pressure engine, the most simple and effective ever known." "It exhibits in construction the most beautiful simplicity of parts, the most sagacious selection of appropriate forms, their most convenient and effective arrangement and connection; uniting strength with elegance, the necessary solidity with the greatest portability, possessing unlimited power, with a wonderful pliancy to accommodate it to a varying resistance; it may, indeed, be called *the steam engine*."

From D. K. Clark's *The Steam Engine*, 1890, vol. iv, p. 647, we take a few paragraphs containing important references:

"It appears that the receiver type of engine was introduced and brought prominently forward by Mr. E. A. Cowper, who states that 'about the year 1838, a small steamboat, the *Era*, had a high- and low-pressure cylinder, with a pipe connecting them and cranks at right angles.'"

THOMAS CRADDOCK'S PATENT UNIVERSAL CONDE
ENGINE.

As applied to the locomotive, with the angular set engine and
connecting rods taking hold of one driving-wheel on each side.



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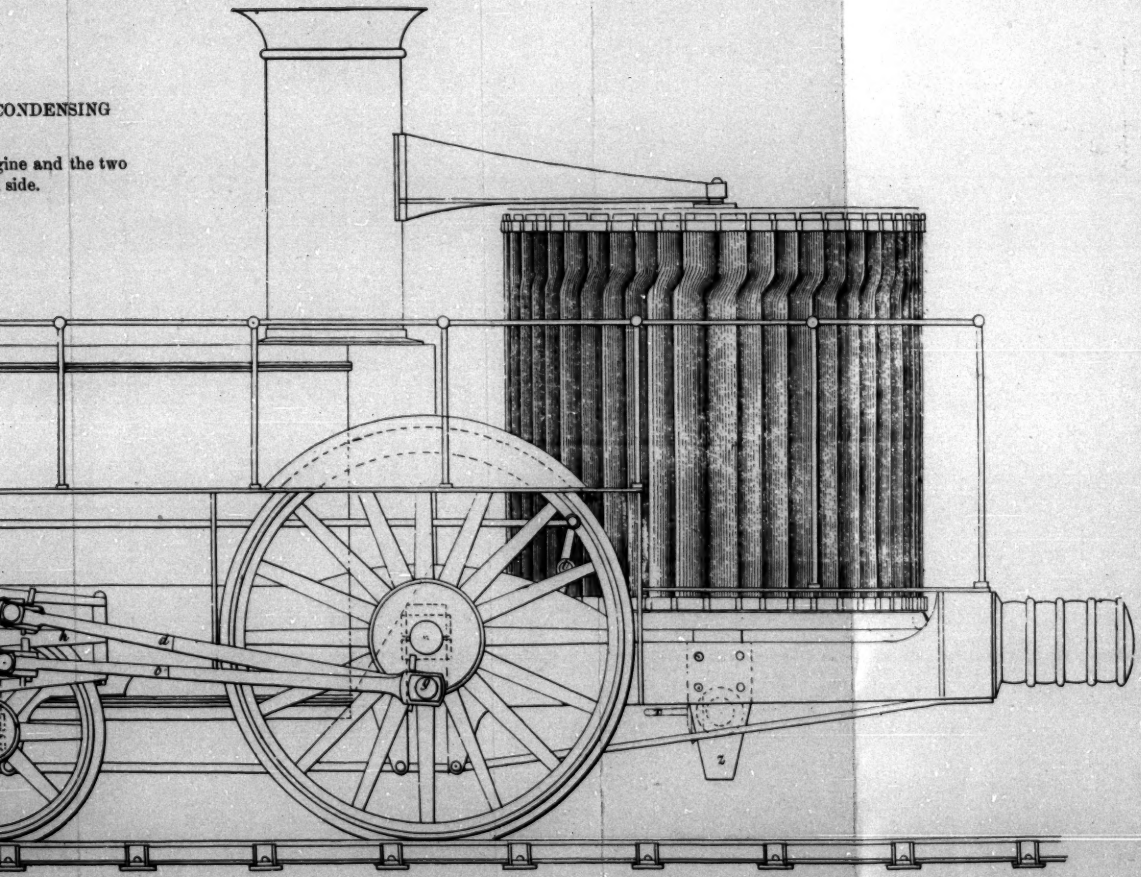

THOMAS CRADDOCK'S PATENT UN
CONDENSING ENGINE.

As applied in locomotive purposes. I
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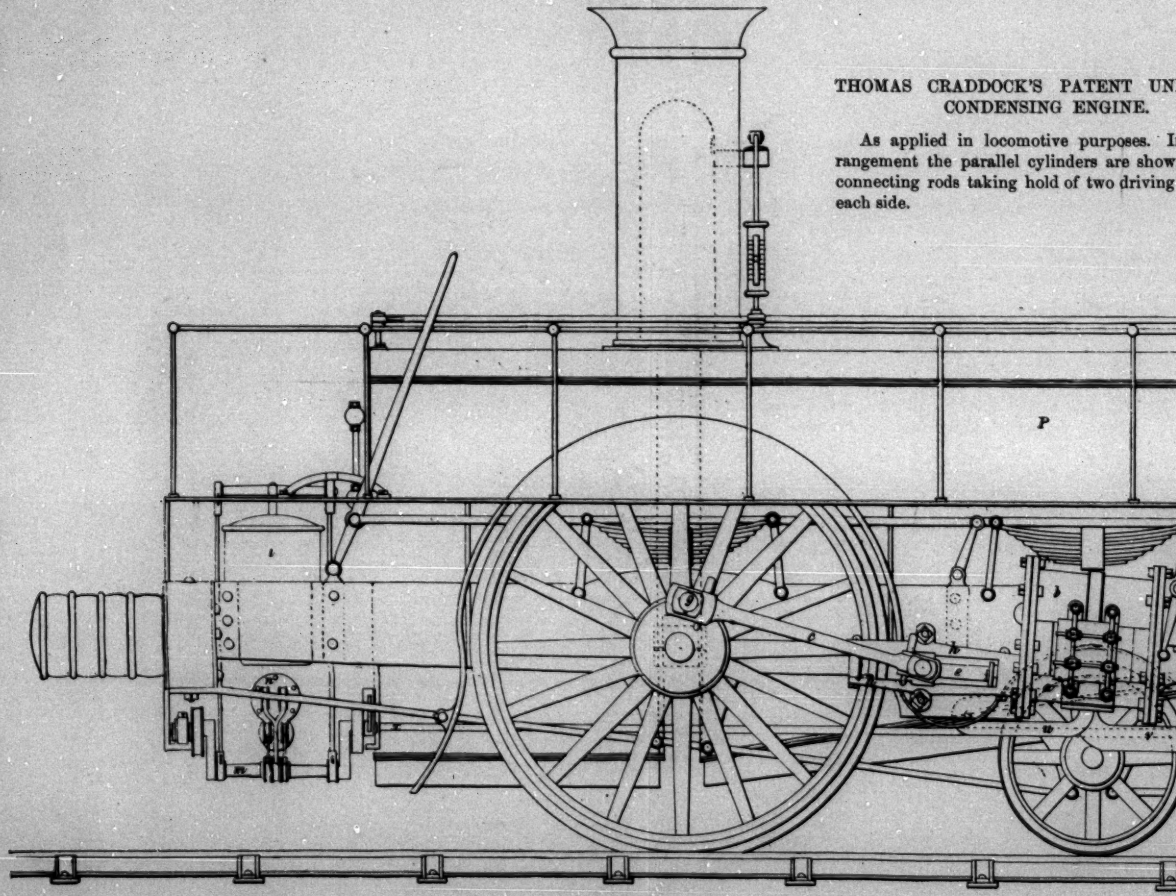
connecting rods taking hold of two driving
each side.



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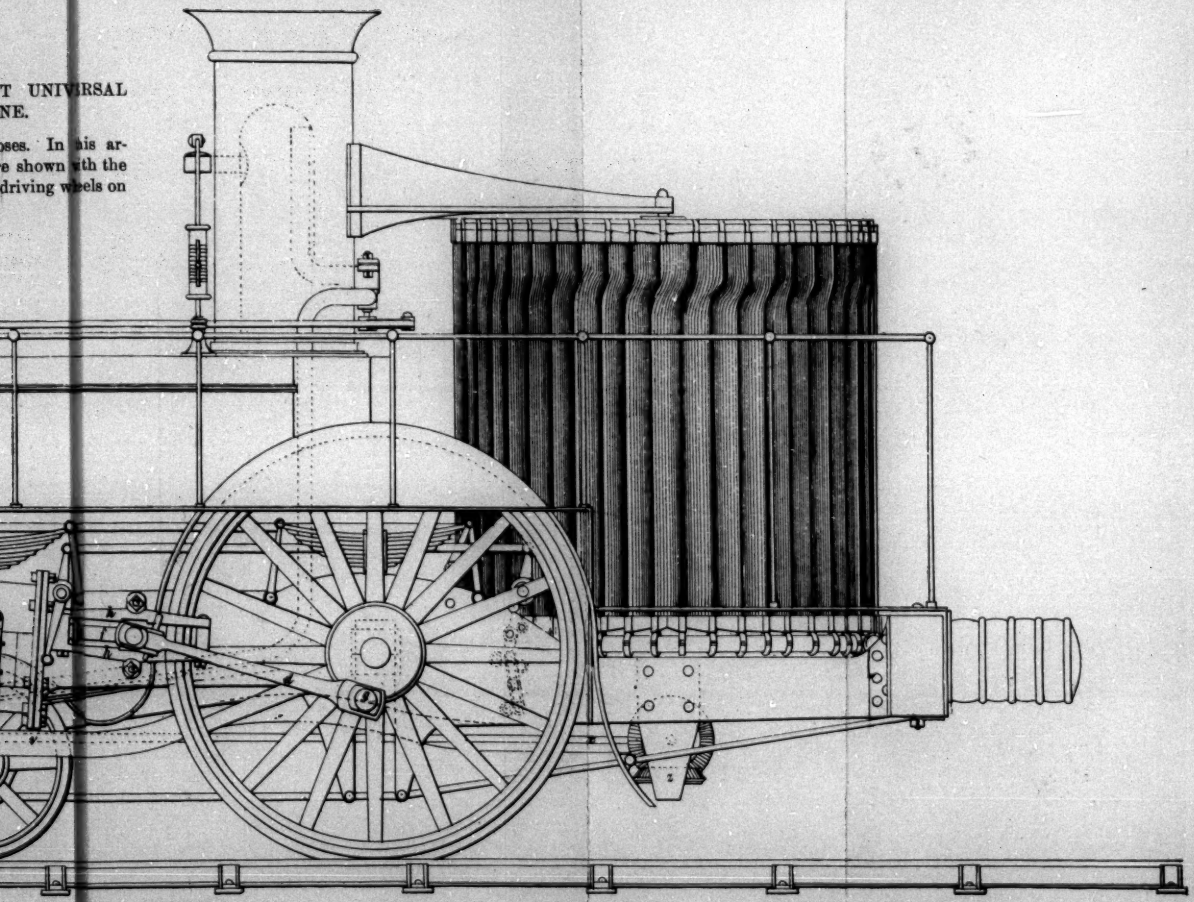

From Mr. Thomas Craddock's book, called *The Chemistry of the Steam Engine*, published in London in 1848, we make the following extracts:

On p. 51 he says: "Owing to the superiority, as it appears to me of two cylinders instead of one for the most economical use of steam expansively, I turned my attention to the combining in the simplest and most compact manner these two cylinders, so as to prevent as little loss of steam, by cooling and useless expansion between the two cylinders as possible. For this purpose I devised what I would designate the *twin-cylinder engine*, having one valve serving for the ingress and egress of the steam into both cylinders. By this means we make *one* eccentric, *one* valve, *one* cross-head, and *one* connecting-rod, with *one* steam-box, serve the purpose of both cylinders."

In the month of April and year 1844, Mr. Craddock made experiments with a compound engine of his own designing, which he says is "the *first* engine ever constructed on the principles I am here treating of, which are those of condensing by *air* with the production of a *vacuum*."

The extent of the vacuum obtained by these means—a revolving fan wheel—was eighteen inches.

"On the application of the invention under discussion to locomotive engines, I have thought much, as we had at one time determined on constructing a locomotive upon the principles I have set forth."

"The best mode, as it appears to me, of applying these principles for locomotive purposes, would be to construct a tubular boiler, having several ranges of tubes." * * * "I should also propose that, to insure the most economical use of the steam, the *twin cylinders*, of which I have before spoken, be fixed much in the same way as the cylinders are at present. We should then have a combination of the high- and low-pressure engine moving itself and a train along our railway." "Another thing to be desired, which would result from such locomotives, as I am here speaking of (with air condensation and return of condensed steam to the boiler again) is, that we should have no noise from, or even *appearance* of steam."

Mr. Craddock further states that, with his twin engine of six and fourteen-inch cylinders combined with his air condenser, by which he obtained a twenty-four inch vacuum, thus realizing his anticipations; he also performed a double quantity of work with the same quantity of steam. "I have fixed upon 115 pounds as the pressure of steam in the boiler, because that is the pressure I have used. But many years will not pass before 200 pounds pressure per square inch will be used, and this with almost total exemption from danger."

Mr. Craddock's patent universal condensing steam engine bears date the 3d of December, 1846, and embodies a claim for the adaptation of double-cylinder engines, attached to separate cranks, to railway locomotives, and a claim for the adaptation of the angularly-set double-cylinder engine, attached to a single crank, to railway locomotives. He further says more specifically, "I claim, in relation to all that class of high-pressure engines in which steam of a high pressure is used in one small

cylinder, and then expanded into a second and larger cylinder, the setting of the cylinders at an angle and connecting them to one crank pin, whether combined or not combined with my other improvements, all or any of them, and in whatever position the said cylinders may be fixed in other respects, as horizontally, vertically or obliquely."

Mr. Craddock's book, published in London in 1847, giving full descriptions of his engines, is illustrated by ten large folding plates of general and detailed views, well and handsomely executed. Three of these plates represent railway locomotives, with two cylinders, a high- and a low-pressure on each side of each engine. In one of them, with parallel-located cylinders, each cylinder is connected to a crank of its own—two to a forward and two to a backward driving axle; in the other, both cylinders on each side, angularly set, so that the axis of each passes through the centre of the driving axle, connect to one crank and to one driving axle; the former having four driving wheels and the latter two, no side rods on either. Illustrations of both these types of construction are given herewith, which sufficiently explain themselves.

Mr. Craddock says: "I ask the reader carefully to note how every principle, which is desirable for economy both in fuel and boiler is embodied in the locomotive represented in the drawing. There we have great extent of grate, low state of combustion, great extent of surface, water free from deposit, the blast not required, the atmosphere removed from the exhaust side of the piston, safety from explosion, every facility for raising the pressure higher at which the steam is generated, a less tendency to priming, every facility for carrying out the expansion principle, the tender dispensed with, the engine of less weight, no steam blowing away at the safety valve, supplies of water not required further than a few gallons per day to make up for leakage. In short, here is every principle requisite to the most perfect, the most economical engine. Never did more sound principles combine to invite a fair trial of any machine than this invention exhibits."

Mr. Craddock proposed to produce steam without blast, by increasing the grate surface to make up for this loss, he would thus secure a quiet running and clean engine. He condensed all the exhaust steam in an enclosed air fan wheel, returning all the water of condensation back to the boiler for reconversion into steam. He used tubular boilers, which afford thin metal, with large extent of surface, supplied pure water to the boiler and thus avoided "deposit," condensed the steam, thus availing himself of the benefit of expansion at the *best* end of it.

The locomotive cylinders have a diameter ratio of 4 : 10 with stroke of 12; driver diameter of 52 and gauge of rails 55½. (No scale on drawings.)

Mr. Craddock certainly conceived many happy engine thoughts, and published much data having creditable simplicity, well worth our study. His theories and principles of construction are well marked with many lines of perfection, and considering date and conditions, his eight years and more of daily experimentation, fraught as they are with results, deserve well of our praise.

Mr. F. W. Crohn, in *Proc. Inst. M. E.*, London, 1879, p. 357, said the "continuous expansion" system was the invention of Mr. John Nicholson (in the year 1850, the same as Samuel's, referred to later on), and engines on that principle were to this day made in considerable numbers at the Blackwall Iron Works for marine purposes.

These engines have been much simplified; they have no receiver and have but one valve to each cylinder, the steam going direct from the high-pressure cylinder into the valve chest of the low-pressure.

The first locomotive built on this system showed an economy of twenty per cent. of coke over ordinary engines, when cutting off at one-third, the work performed being equal in each case, the cylinders were 15 and 17½ inches diameter, giving a ratio of 1:1·36 of area.

Mr. James Samuel's patent bears date April 5, 1850, in which claim 8th describes steam engines adapted for economizing steam and fuel. "Their cranks are placed at right angles with each other or nearly so, and with two or more cylinders. A portion of the steam admitted into the first cylinder is caused to pass into the second, and if more cylinders be used, the steam is passed in both cylinders in succession.

9th. "A hollow slide-valve with metallic packing and springs, to allow steam from the exhaust to pass through the back of the valve." For details, of which see *Mech. Mag.* for 1850, p. 403, London.

Extracts from a paper, by Mr. James Samuel, of London, *on a continuous expansion steam engine*, from Proceedings of the *Institution of Mechanical Engineers*, Birmingham, England, January 28, 1852:

"The economy of working steam expansively is well known, but the application of the expansion principle is practicable only to a limited extent in most forms of engine, from practical difficulties in their mode of working, which prevent the attainment of the full economy of which the expansive principle is capable."

"In the locomotive engine there are practical difficulties in carrying out the expansion principle efficiently, beyond a moderate extent, in a single cylinder, from the shortness of stroke and rapidity of reciprocation and the construction of the valve motion; but the ultimate extent to which it could be carried would be limited by the maintenance of the blast, which requires that the jets of steam discharged from the cylinder into the blast pipe should not be reduced below a certain pressure at the moment of discharge. Otherwise, the limit to which expansion might be carried would be the resistance of the atmosphere to the discharge of the steam, added to the friction of the engine, say about ten pounds per inch above the atmosphere."

"The steam is cut off usually by the link motion at from one-third to two-thirds of the stroke, and the steam is consequently discharged into the blast pipe at about from thirty to sixty pounds pressure above the atmosphere, supposing it to be supplied to the cylinders at 100 pounds per inch above the atmosphere."

"It appears that the lower of these pressures is sufficient, or more than sufficient, for the purposes of the blast, to maintain fully the evaporative

power of the boiler under general circumstances, and that a portion of the steam discharged can be spared from the blast to be subjected to a greater extent of expansion."

"In the continuous expansion engine, the subject of the present paper, the steam from the boiler is supplied only to one cylinder; a portion of it is expanded into the second cylinder, which is of proportionately larger area, so as to equalize the total moving power of the two cylinders; and it is there further expanded down to the fullest useful extent, and then discharged into the atmosphere, the portion of steam remaining in the first cylinder being discharged as a blast at nearly the same pressure as the ordinary engines. The economy, therefore, consists in obtaining from such portion of the steam as can be spared from the blast, the additional power of expansion remaining in it, which is thrown away in the ordinary engine."

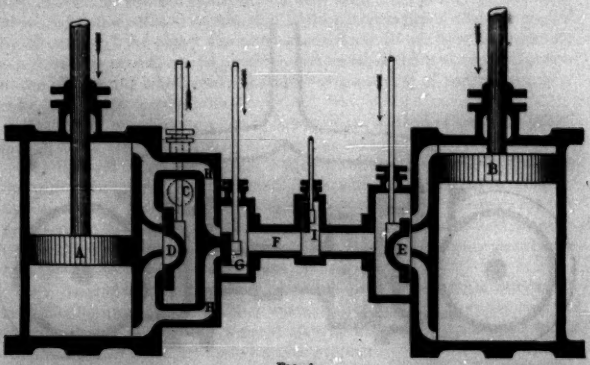

FIG. 4.

Figs. 4 and 5 show the continuous expansion engine as applied to a locomotive. *A* in the first cylinder into which the steam is admitted from the steam pipe. *C*, by a valve *D*, in the same manner as in the ordinary engines. The steam is cut off at half-stroke, and a communication is then opened with the second cylinder *B*, through the passages *H* and *F*, by the opening of the slide valve *G*. The second cylinder *B*, is about double the area of the first cylinder, and the same length of stroke, but the cranks are set at right angles, as in ordinary locomotives; consequently, at the moment of the steam being passed into the second cylinder from the first, the piston of the second cylinder is at the commencement of its stroke."

The steam continues expanding in the two cylinders until the first piston *A* has nearly completed its stroke, when the valve *G* shuts off the communication between the two cylinders, and the valve *D* opens the

exhaust port, and communicates with the blast-pipe *L*, discharging the steam remaining in the cylinder *A*, to form the blast in the ordinary manner. The second piston *B* has then arrived nearly at half-stroke, and contains nearly one-half of the total quantity of steam originally admitted to the first cylinder. This steam is further expanded to the end of the stroke, and then discharged into the blast pipe *L* by the valve *E*, opening the exhaust port.

The return stroke of both pistons is exactly similar to the foregoing, so that about one-half cylinder full of high-pressure steam (or such other portion as may be desired), is supplied to the first cylinder at each stroke, and between one-half and two-thirds of that steam is discharged at the pressure required to produce the blast, and the remainder of the steam is expanded down in the second cylinder, so as to give out all the available power remaining in it.

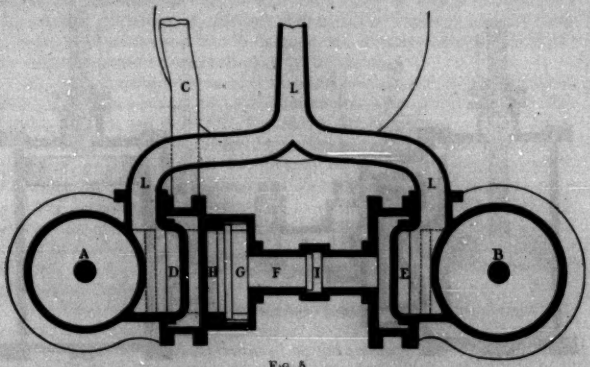

FIG. 5.

For the purpose of enabling the engine to exert an increased power, if required, at the time of starting a train or otherwise, the slide valve *I* is inserted in the centre passage *F* to close the communication between the two cylinders for a short time when required, and the steam from the boiler is then admitted by a pipe and cock into the steam chest of the second cylinder *B*, which is then worked independently of the other cylinder, like an ordinary engine.

"The comparative quantity of steam or of coke required to perform the same work in the several engines, under the circumstances stated above, is given by calculation as follows:

Continuous expansion engine,			100
Ordinary engine cutting off at,	½	stroke,	120
" " "	⅓	"	154
" " "	⅖	"	185
" " "	⅙	"	220

"These figures represent the relative economy in the employment of the steam in the several engines; consequently, the ordinary engine, with the best degree of expansion, or cutting off the steam at one-third of the stroke, consumes twenty per cent. more coke than the continuous expansion engine, to do the same work, and from fifty-four to eighty-five per cent. more coke with the more usual degrees of expansion; and an engine cutting off the steam at only one-eighth of the stroke from the termination, as many engines were formerly made, would consume 120 per cent. more coke to do the same work."

"This plan has been tried upon two locomotives with satisfactory results, and the blast was found to be quite satisfactory, when working the regular passenger and goods trains at full speed.

"One of the engines tried was a goods engine of the largest size, on the Eastern Counties Railway; the valves only were altered, and the second cylinder was not enlarged. It was only a temporary experiment, which, of course, caused a reduction in the extreme power that the engine could exert and the object was more particularly to see how the principle could be best carried out in practice, and whether the proposed reduction in the blast could be effected; the result was a saving of twelve pounds of coke per mile in consumption."

The steam was only supplied to one cylinder instead of two, and therefore so much less consumption of steam would take place.

Mr. Samuel explained that the engine did the same usual work during the trial as before; the engine driver could work the engine in the ordinary manner up the inclines by shutting the communication between the two cylinders, or the engine could not probably have taken the load through the trip, but he might be using more steam than usual in the one cylinder by keeping the regulator more open.

Mr. Samuel further said: That in the two engines that had been tried, no difficulty appeared in making steam, and they were not found short of steam. Goods engines working at slow speed might, perhaps, be found the most useful cases for applying the principle. The other engine that had been tried was a passenger engine, in which the second cylinder was made double the area of the first; and it was never found short of steam, though running an express train of considerable weight. * * * The only definite result obtained was with respect to the sufficiency of the blast, which proved quite satisfactory during the regular passenger train work of about a month.

It was remarked there was one novel circumstance in the arrangement of the proposed engine, which did not appear correct in theory; in all the previous double-cylinder engines, the first piston was allowed to complete its stroke before the steam was expanded into the second cylinder, but in this engine the steam is passed into the second cylinder at the middle of the stroke of the first piston, thereby taking the steam away at the very moment that it is most efficient in the small cylinder.

Mr. Samuel explained that at the half-stroke of the first piston the second piston was at its dead point, and began to move very slowly when

the communication was opened between the two cylinders, and consequently took very little steam, whilst the first piston moved through the greater portion of its remaining stroke; but then, as the first piston was getting less effective and approached its dead point, the second piston came gradually into full action, making a *continuous* expansive action, which was the peculiar feature of this engine, instead of the *intermittent* expansion of the other double-cylinder engines.

This was borne out by the diagram taken; showing a nearly continuous line of expansion from beginning to end of the stroke; and the great uniformity in the total moving power of the two cylinders was shown in diagram also.

For these and other details, see original articles in *Mechanics Magazine*, London, 1850, and the paper quoted above.

Mr. D. K. Clark says that, judging from the results obtained, the capabilities of Mr. Samuel's system of working steam expansively were superior to those of any other that had fallen under his observation.

(*B*) DATA RESPECTING ENGLISH, FRENCH AND UNITED STATES PATENTS, WITH PARTICULAR REFERENCE TO SUCH DEVICES AS RELATE TO THE SUBJECT OF THIS REPORT, ARRANGED CHRONOLOGICALLY.

The foundations of the compound locomotive engine were laid in the year 1776, by Mr. Jonathan Hornblower, who invented and built a steam engine in that year and patented the same in 1781. In this engine the steam, after working in the first cylinder, was exhausted into the second one, which was made larger than the first, thus permitting additional expansion of the steam. In this engine the pistons of both cylinders were connected to one working beam, and, therefore, both pistons moved in the same direction at the same time.

In the year 1838, Mr. E. A. Cowper employed a compound engine, the two cylinders of which were connected by a "receiver" and the pistons were connected to two cranks at right angles to each other. Many experiments were made for determining the proper size of the receiver and the losses of heat by radiation and otherwise.

The direct application of compound steam cylinders to locomotives is clearly and elaborately shown by Mr. Thomas Craddock, and patented by him in the year 1846, but we are not aware that his engines were put upon the road, and for this reason the honor of first inventing and also running a compound locomotive belongs to Mr. John Nicholson (a "driver"). This type of engine was further improved and patented by Mr. James Samuel in the year 1850.

The English patent of Frazer Selby, September 9, 1862, shows annular cylinders proportioned in area, 1 : 4½; also two cylinders side by side of same proportion. There is no provision for starting or of equalizing the total pressure in the two cylinders. His drawings are well proportioned and admirably worked out in detail.

"About the year 1870 the Remingtons, at their works in Ilion, N. Y., built a compound steam car for the Worcester and Shrewsbury Railroad Company for suburban traffic. Two cylinders were used with means of supplying boiler steam to the larger cylinder as occasion required. This engine gave good satisfaction until its withdrawal from service a few years ago." These facts are stated by Mr. W. F. Dixon, of Paterson, N. J., in *Trans. Soc. A. S. M. E.* This is Mr. Wm. Baxter's engine, in which a special slide valve, located in the high-pressure steam chest, was used (under control of the engineer), for admitting boiler steam to the low-pressure cylinder and at the same time permit the exhaust of the high-pressure cylinder to escape into the chimney.

The United States patent of Wm. S. Hudson, dated March 11, 1873, claims:

(1) A superheating vessel, located in the smoke-box.

(2) The arrangement of the smoke-box superheater with connections to the two steam cylinders, such, that live steam from the boiler shall

enter one cylinder and be exhausted therefrom into the other cylinder through the said superheater.

(3) A locomotive having a secondary live steam pipe (provided with a controlling valve which may be operated from the foot board) leading to the second cylinder in combination with the main steam pipe leading to the other cylinder arranged for joint operation, relatively to the boiler.

When the controlling valve in the secondary live steam pipe is closed, boiler steam is admitted only to the small cylinder.

The exhaust from the small cylinder is only through the superheater into the steam chest of the larger cylinder.

This invention provides for no independent exhaust pipe to the atmosphere from the small cylinder. It exhausts only into the steam chest of the larger cylinder, so that if this cylinder were disabled, there would be no means of exhausting from the small cylinder, except through the larger by removing its slide valve.

If live steam be permitted to flow without control into the steam chest of the larger cylinder through the secondary live steam pipe, according to the third claim of this invention, this steam chest being in free communication with the exhaust pipe of the smaller cylinder, there will result a back pressure in the smaller cylinder by reason of boiler steam filling its exhaust pipe.

The consequence of this will be the larger cylinder will do more work than intended, and the small cylinder will do little or no work at all.

There is no hint or suggestion of a means whereby the engineer may know definitely the quantity or the effect of the steam he has admitted to the larger cylinder, and no automatic devices for properly taking care of it.

The English patent of John N. Coxon, June 24, 1874, shows cylinders and valves only. It admits steam to low-pressure cylinder directly from boiler. Exhausts from high-pressure cylinder directly to atmosphere. He claims a hollow valve to permit exhaust from high-pressure cylinder directly through the same to the steam chest of the low-pressure cylinder, same as was done by Samuels in 1850. No equalizing of pressure on the two pistons is mentioned.

The French patent of A. M. Mallet, October 10, 1874, shows a compound locomotive with two tandem cylinders, placed in centre of locomotive under the smoke box.

It is provided with a slide valve, whose chest is outside of the smoke-box, with stem extended to the cab under control of the engineer.

This slide valve, *in one position*, will permit boiler steam to enter the low-pressure cylinder, when the exhaust from the high-pressure cylinder is escaping to the atmosphere, while at the same time boiler steam is entering the high-pressure cylinder as usual when the throttle is open.

In *the other position* no boiler steam can enter the low-pressure cylinder, but the high-pressure exhaust is closed to the smoke-box, and is directed to the low-pressure cylinder, while this cylinder exhausts directly into the atmosphere.

A small spring loaded valve is attached to the steam way to the low-pressure cylinder (in sight of the engineer), so that when it blows off he can regulate the admission of boiler steam to the low-pressure steam chest. This valve is loaded to a pressure of equal to four-tenths or five-tenths the normal boiler pressure.

The English patent of Henry P. Holt, November 6, 1876, uses an automatic intercepting valve between low-pressure steam chest and the receiver. No mention is made of reducing valve to equalize the total pressures in the two cylinders.

The French patent of Alexander Arson, of Paris, May 13, 1878, is a two-cylinder compound engine, having a slide valve, worked by an eccentric which is operated by hand for regulating the flow of live steam into the steam chest of the low-pressure cylinder for starting.

The English patent of Thomas Robertson, January 1, 1881, is for a two-cylinder compound provided with means of injecting a jet of boiler steam into the low-pressure cylinder. No mention of steam reducing valve.

The United States patent of Henry D. Dunbar (a four-cylinder tandem compound locomotive), dated April 24, 1883, is provided with an independent *D* slide valve (on three ports) moved by the engineer in the cab, to admit boiler steam to the low-pressure cylinder, and permit the high-pressure cylinder to exhaust into the atmosphere at the same time. This was done precisely in the same manner by Mr. Baxter in 1870. No mention is made of an equalizing pressure valve for the low-pressure cylinder.

The English patent of Edwin Foden for a compound traction engine, July 23, 1885, claims:

"In compound engines, having either one or more high-pressure steam cylinders in combination with one or more low-pressure steam cylinders, the use of a three-way cock, or its equivalent, for the purpose of temporarily suspending the compound action of the high-pressure steam cylinder and the low-pressure cylinder, so as to cause each cylinder to receive its steam direct from the boiler, and to exhaust its own steam direct into the atmosphere, or independently, so that the low-pressure cylinder, does not then take the exhaust steam from the high-pressure steam cylinder, but becomes for the time being an additional high-pressure steam cylinder."

Mr. Foden's drawings do not show a reducing or relief valve, nor does he lay claim to such a device; but he prefers to provide the steam box of the low-pressure cylinder with one to reduce the pressure within.

The English patent of Richard C. Parsons, August 3, 1886, provides a valve which opens the high-pressure exhaust to the atmosphere. This valve is normally held close by a spring, but is opened by steam upon a piston connected with the valve, which piston is controlled by the engineer by means of a pipe and a cock.

Another drawing shows a second valve which admits live steam to the low-pressure cylinder and at the same time opens high pressure exhaust to the air. There is no mention of an equalizing pressure valve.

The English patent of Wm. Hornsby and Fred. J. Cribb, November 25, 1886, exhibits a slide valve, operated both ways only by the engineer from the cab, for admitting live steam to both high-pressure and low-pressure cylinders and opening the exhaust of the high-pressure cylinder to the atmosphere when starting.

The United States patent of Thomas W. Worsdell, dated April 5, 1887, following his English and French patents, says: "One of the cylinders takes steam direct from the boiler. When this steam is exhausted it passes through a superheating pipe to the low-pressure cylinder. After performing its function therein, the steam from the low-pressure cylinder is exhausted direct up the chimney."

"To render the engine efficient in starting, a starting valve is provided by which steam can be conveyed direct from the boiler to the low-pressure cylinder, and in order to prevent such steam filling the exhaust steam pipe of the high-pressure cylinder, and consequently the high-pressure cylinder itself there is provided a valve that I call the 'intercepting valve.' When closed this intercepting-valve will prevent the live steam getting back to the high-pressure piston. A flap-valve is preferred as it can be closed at will, and will always be thrown open by the steam itself when exhausting commences from the high-pressure cylinder. The starting-valve may be arranged to be opened by hand against a spring, so as when liberated to be closed in an automatic manner. The low-pressure cylinder is fitted with a relief valve at each end, to prevent the cylinder being charged at too high a pressure when steam is admitted direct from the boiler through the starting-valve."

No means are provided for running this engine continuously as a simple one, and no device shown or described for proportionally reducing the live steam pressure in the low-pressure cylinder.

The United States patent of August Von Borries, dated April 19, 1887, after seven foreign patents for the same invention, has for its object the construction of a two-cylinder compound locomotive, such that the connection between the cylinders can be cut off and both be worked at high-pressure when desired. An automatic valve is used for intercepting the high-pressure cylinder exhaust pipe and in the same movement of this valve, when it closes, a small live steam opening is made into the low-pressure cylinder steam chest. The moment this valve opens, by accumulated pressure in the high-pressure cylinder exhaust pipe, the live steam openings are closed and the engine goes at once into compound working.

There is no provision for continued simple running and no means for equalizing steam-pressure upon the two pistons.

The English patent of Halpin and Timmins, July 14, 1888, claims: "In a two-cylinder compound locomotive; a starting valve, consisting of a double seat valve loaded directly by a coil spring and allowing (on the engine being started), high-pressure steam from the boiler to pass directly into the low-pressure cylinder, until the back-pressure of the steam in the receiver and that of the spring, which act on the top area of the valve,

exceed the pressure of the boiler steam, acting on the lesser area of the underside of the valve, in consequence of which the said valve drops back on its seat and then the engine works compound."

In Robert Lindner's United States patent, May 28, 1889, the remark is made, that: "It is necessary, in locomotives in starting the engine that steam of a reduced pressure direct from the boiler be admitted to the low-pressure cylinder, in order that the low-pressure cylinder should start the engine."

To accomplish this result, he provides a cock in a small branch pipe for admitting boiler steam to the high-pressure cylinder exhaust pipe, connecting the lever of this cock to the reverse lever and constructing the cock so that it shall admit steam only at the extremes of its stroke. He also forms small vent holes on the inner lips of the high-pressure cylinder slide valve, which in the middle of its travel, relieves the high-pressure piston from unequal strain, by opening both ends of the cylinder to the exhaust pipe for a moment, while the valve is passing. No device is mentioned for equalizing the steam pressure in both cylinders other than by wiredrawing it into the low-pressure cylinder.

The United States patent of J. Lewis, dated June 11, 1889, consists of four parallel cylinders, under the smoke-box, the steam to all of them is controlled by one rotating elastic valve, centrally located. One high-pressure and low-pressure cylinder on each side of locomotive is connected to one cross-head, with one connecting-rod to the crank.

One valve, controlled by engineer, for admitting boiler steam to both low-pressure cylinders at starting.

No mention is made of independent exhaust for the high-pressure cylinders at starting, and no allusion to, nor provisions for, equalizing the pressure of steam upon the pistons, when live steam is used in low-pressure cylinders.

The elastic valve will permit unequal compressions in the cylinders to escape.

The power of the high-pressure cylinder is necessarily weakened when live steam is admitted to the low-pressure steam chest.

The United States patent of Richard H. Lapage, dated July 8, 1890, following his English patent is for a three-cylinder compound locomotive, in which, however, the *two* low-pressure cylinders act as one, being connected to one cross-head and receiving the exhaust steam in the usual way from the one high-pressure cylinder.

The only object of duplicating the low-pressure cylinder is, the specification says, to avoid the danger of "fouling the loading gauge, existing platforms, tunnels, and the like." "By this means the use of a large overhanging low-pressure cylinder is obviated." About this, we have proven, there is no real concern, as there is room, by proper designing, for any *required* single low-pressure cylinder.

In this engine there is no independent exhaust way to the atmosphere for the high-pressure cylinder; no means of continuous single running and no suggestion even of devices for equalizing the steam pressures in the high- and low-pressure cylinders.

The United States patent of Albert J. Pitkin, dated April 14, 1891, covers an intercepting valve operated by "live steam to close it and shut by pressure of the steam in the low-pressure cylinder."

9th claim: "A valve controlling the admission of live steam to the low-pressure cylinder and automatic mechanism for positively opening said valve;" that is, it is actuated by the intercepting valve.

No mention is made of, nor drawings show, an automatic pressure-equalizing valve.

The United States patent of Francis W. Dean, September 22, 1891, covers an automatic intercepting valve working vertically.

"The construction insures the opening of the converting valve before the pressure of exhaust steam in the high-pressure exhaust passage accumulates above the receiver-pressure and thus relieves the high-pressure piston of the early back-pressure."

"The intercepting valve opens in advance of an accumulated back-pressure on the high-pressure cylinder to any desired degree."

No mention is made or drawing to show an automatic pressure reducing valve for low-pressure cylinder.

This patent proposes to admit live steam to the low-pressure cylinder at the same time live steam is admitted to the high-pressure cylinder to facilitate starting. This is done through the intervention of an intercepting valve and a converting valve, both of which are vertically opened and shut.

When boiler steam is admitted to the receiver by which to run the low-pressure cylinder as a simple engine, the intercepting valve closes, so as to prevent this steam from filling the exhaust pipe of the high-pressure cylinder which would reduce or destroy its power.

There is no separate exhaust pipe to the atmosphere shown or described, for the high-pressure cylinder.

There is not a word said about the necessity of, nor a contrivance for equalizing the total pressures of steam upon the two pistons, when both are working as simple engines.

(C) NOTES, DATA AND REFERENCES BEARING UPON AND RELATING TO THE USE OF STEAM IN COMPOUND LOCOMOTIVES AND OTHER STEAM ENGINES.

In the preparation of this report, your committee has extended its searches and has presented a wider range of subjects than is usual in such cases.

This procedure is desirable in view of the increasing interest taken in the compound system of locomotive construction.

The advisability of detailing the means which have been employed to adapt the two-cylinder compound steam engine to the popular two-cylinder type of locomotive, has been considered to be right and proper in this connection since this type out-numbers all others.

Experience with locomotives, everywhere, has shown the advantages of simplicity of construction in all the working parts; this committee, therefore, has dwelt at considerable length upon such details and methods, as

have contributed to economy, without increasing the number of parts used for transmitting the power of the steam to the driving wheels.

The volume of railroad service having grown to such unprecedented magnitude, we feel that whoever contributes to it, or reduces the cost of its maintenance, confers a lasting benefit upon mankind.

There is no claim made by Mr. Batchellor for a two-cylinder compound locomotive by itself considered.

It is well known that the first two-cylinder compound engine was invented and built in England by Jonathan Hornblower, in the year 1776, and was patented by him in 1781, as stated above.

It is also on record that one John Nicholson, an English "engine driver," devised and run a two-cylinder compound locomotive on an English railway in the year 1850, since which time numerous patents have been granted for two-cylinder compound engines adapted to stationary and locomotive use, and with attachments for various purposes. These attachments differ according to the conception of their inventors, and the service to be rendered by their inventions.

The question of the objectionable width of two-cylinder compounds, due to the increased diameter of low-pressure cylinder is answered by the fact that numerous engines of this type are now running in this country and abroad. Builders of engines are now making two-cylinder compounds, even of the heaviest type, and officers of several of our roads who are responsible for their performance are having them made.

As to clearance width of locomotive, from the *Locomotive Engineer*, for November, 1891, p. 206, we take the following:

"The question of the application of the two-cylinder compound locomotive, such as used in heavy service for both passenger and freight traffic, is answered by the Schenectady Locomotive Works' people, who have already built a number of the two-cylinder type, and have designed a heavy compound consolidation engine of equal capacity to the 22 x 28 inch cylinders on the Union Pacific, which are believed to be the largest and most powerful locomotives at work in regular road service at the present day.

"The low-pressure cylinder is thirty-two-inch diameter, yet the extreme distance outside of cylinder does not exceed that of other two-cylinder compounds now running.

"The design demonstrates the fact that the popular two-cylinder type of compounding can be applied to the heaviest locomotive in road service at the present time."

We have found on inquiry, that every superintendent of motive-power, or master mechanic in this country, who recently has built a compound engine, or rebuilt a simple engine by changing to compound, has in every case used the two-cylinder type.

So for example, Mr. Lander, of the old Colony, and Mr. Mitchell, of the Lehigh Valley, each is building a Dean. Mr. Stevens, of the Lake Shore, has had the Brooks Locomotive Works to build a two-cylinder engine; the C. B. & Q. has built one, and are now building two more of

this two-cylinder type. In addition to these the Southern Pacific and the Atchison, Topeka and Santa Fé have done the same.

If there was any serious objection to this type of engine, due to its greater breadth, it is fair to believe these men would not order them built.

The Rhode Island Locomotive Works say: "In regard to the clearance width of the two-cylinder type of compounds there is no trouble whatever in going as high as a thirty-one inch diameter for the low-pressure cylinder, which is equal to about two and one-half times the area of the twenty-inch high-pressure cylinder. This proportion we consider is near right as it is possible to get, and we think that by taking a little pains in the designing, we could get even a larger cylinder than thirty-one inches, but have had no reason to look into the matter any further than this, as the twenty-inch cylinder for the high pressure is as large as anything that we have built on our largest consolidation engines, so that we do not think there is any ground for complaint on this score."

A contributor to the *Railroad Gazette*, for August 21, 1891, p. 575, says of two-cylinder compounds, in answer to the main objection, that "the cylinder ratio could not be made large enough, and room still be found for the cylinders within the permissible width of the locomotive." He not only proposes to offset the centre of the low-pressure cylinder to a point within the centre of its application on the crank pin, which, however, is proven unnecessary by references to replies given herein, but further asks, why not increase the diameter of the high-pressure cylinder and expand the steam more in that which would also help the engine in starting?"

"It is being generally conceded that the difficulty with the two-cylinder engine (he refers to certain existing types) is that after the first exhaust of the high-pressure cylinder, when it should be exerting a comparatively high-pressure on the crank pin, it is not doing so, because of the back pressure in the receiver, and when working compound the two-cylinder locomotive has not as much average total pressure on the piston as the simple engine which it was built to replace."

"This has resulted from following an empirical rule; that is, to make the high-pressure cylinder *one inch larger in diameter* than the cylinder of the simple engine of equal power; this is wrong."

"The two cylinder is really the simplest and most desirable type of compound locomotive."

Mr. Thomas Urquhart, *Proc. Inst. M. E.*, London, 1890, p. 60, says: "The results of the author's experience are such as to leave no doubt in his own mind that compound locomotives are the engines of the future in all countries. "What is really wanted, is to mature a thoroughly efficient *two-cylinder compound with moving parts as light as possible, and well balanced.*"

It is not worth while to consider the objection to weakened draft in the chimney by reason of diminished exhaust pressure and reduced number of exhausts, because all the compounds are running satisfactorily, with good steaming qualities.

In Mr. W. Fletcher's work on *Steam Locomotion on Common Roads*,

London, 1891, we find the following in reference to the Messrs. Fowler's recent type of compound road locomotive: "By the use of a low-pressure cylinder working in conjunction with a high-pressure cylinder, the greatest possible amount of expansion is obtained, and almost all the power in the steam is used before it is discharged into the atmosphere, the pressure of the exhaust steam being only eight pounds, which is just sufficient to create a draught necessary for the combustion of the fuel.

"These engines will do the same amount of work with thirty per cent. less fuel and water than the ordinary engines in every-day use. In consequence of the steam passing from these engines into the atmosphere at the low-pressure of eight pounds, the noise caused by the exhaust and all dangers from sparks are avoided." The road locomotives of other builders in England have performed equally as well.

We have all been taught by long existing practice to believe that a locomotive boiler will not make steam enough for the needs of the engine, without blowing all the exhaust steam from both cylinders at high-pressure tension into the stack, and that any reduction of its strength would materially lessen the generation of steam. See Samuel's continuous expansion engine for proof of the existence of this belief prior to the year 1852, where part of the high-pressure exhaust steam and all from the low-pressure cylinder went for blast.

From Mr. J. Samuel's supplementary paper on his continuous expansion steam engine, we quote:

"As far as they went, however, they showed that the blast could be reduced without impairing the efficiency of the engine. In a goods engine of the largest size, on the Eastern counties, the valves were altered, but the cylinders were retained both of the same size, and the result was a saving of twelve pounds of coke per mile. In a passenger engine, the low-pressure cylinder was made double the area of the high-pressure one, and it was never found short of steam, though running with express trains of considerable weight for a month's regular work."

In M. Mallet's two-cylinder compounds, three of which were in service prior to May, 1878, employed on local traffic and at times running twenty-five miles per hour. "The draught was ample, so that the boilers in spite of small dimensions supplied the wants of the engine abundantly."

From the above statements, it would appear useless to consider this objection, because all the engines fitted with low-pressure blast are now running satisfactorily in this particular, and we may safely add the remark here that, as the Rhode Island compound can be run as a simple engine, at any time and for any length of time as a simple engine, with the full blast efficiency, due to simple running, there need not be any lack of rapid steam generation for want of known means for doing it.

Furthermore, there is less steam to be made if compounding saves some of it, and in any case, *all that is made goes through the stack.*

To answer the question as to the value of superheating the exhaust steam on its way to the low-pressure cylinder as patented by Hudson, reference is made to the results of experiments, conducted by the C. B. & Q.

R. R. Co., who concluded that the cost of maintenance was more than the advantages gained.

This has nothing to do, however, with extending the pipes through the smoke-box, which is the most direct course, has many constructive advantages and keeps them in a closed chamber heated to from 400° to 1,000° of temperature, which is, perhaps, the cheapest method of clothing them.

Mr. T. Moy (in *London Mech. Mag.*, for August, 1863), proposes to increase the efficiency of the heating surface of steam boilers, "by increasing the *surface in contact with the water*, without a further increase of the absorbent surface." He further says: "It is pretty generally known that flanges cast on air-warming apparatus, greatly increased the effect of such apparatus, the cause being that a greater surface of heated metal is in contact with the air." His plan is to form flanges on the outsides of the tubes. Whether this will be as effective when the heat is required to pass in a reverse direction, remains to be proven.

Mr. W. F. Dixon, of Paterson, N. J., in vol. xi, of *Trans. Amer. Mech.*, p. 870, on the "Efficiency of Locomotives," says: "The C. B. & Q. R. R. Co. between 1870 and 1874, went fully into the subject of superheating. In these experiments the front tube sheet of the engine was set back into the barrel of the boiler some distance from its normal position. In the space thus left was fitted a separate cylinder, filled with tubes, through which the products of combustion had to pass on their way to the atmosphere. The dry pipe entering this cylinder at the top, and the steam, after circulating among the tubes and becoming superheated in doing so, passed to the cylinders of the engine through pipes connected to the bottom of the superheater.

"The resulting economy was, however, more than offset by the expense of keeping up."

The most conclusive test of the compound locomotive is that which is made in road service by the rank and file of engine men, extending over considerable mileage, under the usual varied conditions of present practice and with conditions precisely alike.

Your committee is satisfied that this method of experiment and comparison has been fairly carried out in the cases before us.

This committee decided that we should make personal inspection of these locomotives; we take pleasure in repeating here the report upon their performance by one of its members:

"I was in New York on the 15th of March, 1892, and went over to Brooklyn to see the two-cylinder compound locomotive running on the Kings County Elevated Railroad. This engine was built by the Rhode Island Locomotive Works, and has been running several months. Went to the General Manager's office where was shown the performance sheets of their engines, and when the engine came along we got on and rode to the Ferry and then back to the terminus of the road (nearly eight miles) and then back again to the Ferry and then again up the steep grade (which is 180 feet per mile), where it acted as a helper for another engine.

"During this whole time the engine performed its duty to the *entire*

satisfaction of everyone, showing no more trouble to operate than a simple engine.

"It *rides well*, and were it not for the *absence* of *noise*, *sparks* and *dust*, one would not know that he was on a compound engine. It is using a nozzle four inches in diameter and steams freely with the door partly open, nearly all of the time.

"There was not a single moment during all of my ride where any of the arrangements that are used to change from simple to compound showed any desire to give trouble, but on the contrary, they all responded promptly. The trip was a very pleasant and satisfactory one."

In estimating the economy of various types of compounds employed on different roads, care must be taken to note all the conditions of running, which may greatly affect the comparative result.

Engines built and used for yard work and suburban traffic which are well nigh all stops and starts, with very short spaces for compounding, must not be paralleled with express engines on long runs, with a clean sweep the whole distance for compound running.

We must beware of incongruous comparisons.

Mr. Angus Sinclair (Sec. Am. Rwy. Master Mechanics Assoc'n) says, in the *Trans. Soc. A. S. M. E.*, in article on the "Efficiency of Locomotives," by W. F. Dixon, 1890, "few engineers would allow themselves to be influenced by results which are not obtained in road service."

Your committee has considered the figures of coal saving from various authorities.

	Per Cent.
The first compound locomotive run in the year 1850 and Samuel's continuous expansion engine of 1852, saved in coke,	20
Fowler's traction engines. English, saved,	30
Foden's " " " "	29 1-10
Burrell's " " " "	30
Worthington's non-condensing steam pump,	30
Worsdell's compound locomotive on English Railroad,	18 to 25

Mr. Urquhart made various numerous experiments with petroleum fuel on five compound locomotives and an equal number of non-compounds during five summer months, which showed a saving in favor of the compounds of from 18·22 to 18·96 per cent. of such fuel. He also gained an economy of repairs on the passenger locomotives, equal to 49·2 per cent., and 28·8 per cent. on goods locomotives.

In reference to the valves used for reducing the pressure of steam when directly employed in the low-pressure cylinders, which are necessary to prevent over-pressure in the same, and equalize the steam action in both cylinders, your committee has not found any other in use that fulfils this important requirement to any noteworthy degree, like that one applied to the compound locomotives built by the Rhode Island Locomotive Works.

Many of the earlier and later methods of preventing an excess of live steam pressure in the low-pressure cylinder are by wire-drawing the steam through small pipes and drilled holes, which are opened and closed by the engineer or by automatic action of other valves, which control also the

exhaust ways. Some prevent over-pressure by spring-loaded snifting, safety relief valves or slide-valves. Wasting the steam in the atmosphere within sight of the engineer, who will know by this escape that the cylinder has overmuch of steam, and can act accordingly.

Whatever kind is used, and the presence and absence of them will be noticed in the detail of the several devices and patents quoted.

Your committee does not believe that the mere suggestion of and use of a pipe with a connected cock or valve for admitting steam to *anywhere*, merits notice of novelty at our hands, nor does a spring loaded safety or relief valve for giving notice of over-pressure or danger claims special attention in an inquiry of this nature.

Your committee is fully persuaded that in the design and construction of a compound locomotive they should be made as simple as possible.

With the adoption of two cylinders the number of working parts will be reduced to a minimum; the steam ways and everything else appertaining to the employment of the steam in the machine will necessarily be the least intricate, and will in turn reduce first cost and maintenance.

Mr. Alexander Borodine states, in *Proc. Inst. M. E.*, London, 1886, p. 353: "Considering that the compound locomotive with which the experiments were carried out, involves scarcely any complication and that it costs about the same to build as the ordinary engines and that a decrease in consumption of fuel lessens the cost of boiler repairs and of providing feed water, etc., it may be concluded that there is an undoubted advantage in building locomotives on the compound system."

Your committee readily assents to this proposition. One of them, more than ten years ago, announced the fact that a compound land engine could be built for same money as the usual high-pressure non-condensing engines then built; the saving in boiler capacity and equipment fully pays for the necessary additions to the engine.

The economy of short steam passages by which "much waste of steam is avoided," and the exposure of "less surface is presented for atmospheric resistance and cooling—a very important consideration at high speeds," are points claimed by Mr. Joseph Lewis in his United States patent of June 11, 1889.

In the English patent (1889) of J. T. A. Mallet, mention is made of his preference for two cylinders "both for simplicity of construction and to avoid an excessive amount of cooling surface."

On the subject of the economy of steam expansion and loss of power by radiation, Mr. Robert Stephenson said "that in the 'Planet,' one of the early locomotives made in 1832, he had the cylinders carefully enclosed inside the smoke-box instead of being outside, and there was found to be a considerable increase of power effected by the plan. That was the first locomotive constructed with heated cylinders, and it appeared the principle ought never to have been deserted." (*Proc. Inst. M. E.*, 1852, p. 85.)

Mr. D. K. Clark found by the indicator diagrams "that a great condensation of the steam took place in exposed outside cylinders during the first part of the stroke, from the coldness of the cylinders, and a consider-

able amount of condensation also was caused even in protected cylinders, where they were not artificially heated by exposure to the hot air in the smoke-box, because the temperature of the mass of the metal in the cylinder remained about the mean temperature of the steam while expanding in the cylinder, which might be many degrees below the original temperature of the steam on entering from the boiler." (*Proc. Inst. M. E.*, 1852, p. 87.)

Mr. Cowper "thought there would not be found to be any loss by condensation in a well-protected cylinder; he had not found any to take place in the experiments that had been tried on expansion."

"With respect to Mr. Samuel's mode, lately patented, of working steam expansively to a degree contemplated at four to six times the initial volume, by exhausting from one cylinder into the other, it is plain that the necessary conditions for the economical employment of such an extent of expansion, demand a much better provision for the preservation of the steam than is to be found in the ordinary arrangements of outside cylinders. According to Mr. Samuel's designs, the cylinders are placed outside in the usual manner, without any expedient for preserving the temperature of the steam; and it is easy to understand that special means must be adopted for this object, to secure an economical promotion of expansive action to the extent peculiarly available by his system."

D. K. Clark, *Railway Machinery*, London, 1855, p. 84.

"Mr. Stephenson mentioned an experiment by Mr. Trevithick, in which he found that *one* bushel of coal burnt under the cylinder did as much duty as *five* bushels of coal burnt under the boiler, showing the economy of keeping the cylinder warm." (*Proc. Inst. M. E.*, 1852, p. 131.)

"The annular cylinder compound engine, worked with one slide valve, was originally proposed in 1837 by William Gilman, and it has for many years been used by a London engineering firm in the construction of engines to drive corn mills. But the writer (Fred. J. Bramwell, of London) believes that care has never been taken to steam-jacket the high-pressure cylinder, which has thus always been bathed in an atmosphere of the low-pressure steam; this the writer looks upon as the cause of considerable loss." (*Proc. Inst. M. E.*, 1872, p. 147.)

To the above observation we may add our own: If there is loss in expanding too far in one cylinder, by which the departing steam lowers the temperature of the cylinder below that of the incoming steam, then, indeed, a high-pressure cylinder entirely surrounded by low-pressure steam must be at a great disadvantage.

Watt's grand invention consisted in condensing in a separate vessel, his aim being to economize by keeping the cylinder "always as hot as the steam that entered it."

The transition of this happy thought to the kindred one of *expanding in a separate vessel* seems not to have been made, although embodied in Hornblower's invention. On this occasion Engineer Blunder sat upon the Wishing-gate.

This subject was earnestly studied and widely published by Craddock

in the year 1840, and later on, who showed clearly the advantage of preventing high-pressure steam from coming in contact with the walls of a vessel from which low-pressure steam was escaping, and who also proved his theory to be true in practice by making a twin-cylinder engine which performed double work with the same amount of steam. As modern compound engine practice has made this matter as familiar to us as office words, we need no labored argument for demonstration of it; we can only wonder why a matter so simple was not taken advantage of long before.

We must understand once for all that expansive working of steam is not a *gain* but a *saving*. The want of a proper understanding of this difference may have been the cause of the diverse views which have been held upon this subject by prominent engineers.

Economy goes with the expansion of steam, and with least steam waste which are secured by proper proportioning of the cylinders to the work to be done, and by efficient clothing of the exposed steam chambers.

There is no reason for useless loss of steam on its way to work, when there are well-known methods of saving it.

Experiments prove that a well felted boiler will save twenty-five per cent. of fuel over an exposed one; even an open door sensibly affects the running of a stationary engine; then why are not locomotive cylinders seriously affected when the storm door is always wide open?

Proofs are already abundant that economy in the use of steam runs in the line of continued expansion in more vessels than one; we were told this just 116 years ago, and we are slow at learning the lesson and putting it in practice.

About the same time Cornish men told us that best clothing meant increased saving of steam.

It has always seemed strange that a weather-chilled railroad man never applies the same reasoning to his exposed steam cylinders that he promptly does to himself, the object being the same in each case—the retaining of heat.

The hydraulic engineer soon finds out that he must avoid sudden contractions and enlargements and sharp turns in the water-ways of his constructions.

All this speaks plainly to the engineer: Save your steam when you have made it against loss due to radiation, and spare it from needless resistances while passing from the generating vessel to the point of application.

Of all things provide that your steam shall act quickly, and this is effected most perfectly by the least number of parts and ways through which it is to flow.

In order that the points of these statements may be clinched, as applied to the subject before us, we repeat Watt's golden rule: "The supreme excellence of machinery is its simplicity." We further quote from one of our best English authorities on steam and on the machines in which it is employed:

"There is a peculiarity in the double-cylinder engine, in its requiring a

pipe or passage of some kind, through which the steam must travel, from one end of the small cylinder to the opposite end of the large one; and this passage should evidently be as small in content as possible, consistently with allowing the free passage of the steam."

"When the communication is opened at the end of the stroke, the steam, passing from the small cylinder, has to expand and fill the passage before it enters the large cylinder; and if the passage be large, the steam must necessarily suffer a reduction of pressure in so doing, which must seriously diminish its effective action on the large piston during the future stroke, and so cause much loss."

"In some engines, the author found this loss so great as to waste nearly half the power of the engine; and even in the best that were examined, such a considerable percentage of loss occurred, as almost to neutralize the expansion altogether."

"Much attention was therefore given to this point in designing the new engines: and it was found essential to the success of the engines that some arrangement of valves should be adopted which should satisfy the following conditions:

(1) That they should be of the simplest possible character and free from liability to derangement.

(2) That they should admit of the steam being cut off from the small cylinder at such a point as might be necessary to secure the required regularity in the motive-power of the engine.

(3) That they should give the clearance spaces the smallest content possible, and in particular, should allow the passage between the two cylinders to be direct and unimpeded, and of no larger capacity than was absolutely necessary for the passage of the steam."

"It was further found conducive to economy that the passage between the two cylinders, should, if possible, be carefully protected from cooling." Wm. Pole, from *Newton's London Journal of Arts*, August, 1863.

The fact is well known to every locomotive engineer that the requirements of a locomotive differ wholly from those of a stationary engine.

The conditions vary continually.

When starting a locomotive its greatest power is needed, this may also be needed to overcome occasional resistances at any time along the roadway. That locomotive, therefore, which is supplied with mechanism, at the will of the engineer, capable of running the engine at full power at any time and for any length of time, and as easily convertible into compound running, must take the precedence over every other.

For elevated railway, rapid transit service, such locomotives as the two-cylinder Rhode Island type is admirably adapted.

Their extreme cleanliness and quietness, easy riding and economy of oil commends them highly for service in cities.

Their economy in the use of fuel and water, combined with the lighter carriage of these requisites, and a more even distribution of the application of their power to this kind of service, which is conducted upon structural highways, possess many advantages.

The ease with which these engines are thrown into simple working, having full pulling power, as becomes necessary at certain times of the day, when the flood-tide of travel is all going one way, and as happens on many roadways, these extra heavy loads must be taken at full speed, up and over long and steep gradients, and when these are passed, a simple turn of the hand will change to compound running.

A compound locomotive, with multiple cylinders, is not built for the sole purpose of getting more power; the chief object to be gained is the saving of steam, which can be done in two cylinders, as commercially well as in any greater number on a locomotive.

In all cases, whether two or more cylinders are used, it is generally understood that in order to secure good results, the cylinders are proportioned to the weight on the driving wheels, and to the pressure of the steam.

We are more concerned here, however, with the appliances by which any type of compound locomotive may be made *universally applicable* to *any* road and to *any* service.

This invention is not simply ingenious, although it takes rank with any having high merit in that particular, but the merit we desire to report favorably upon, and give award to, is of such character as possesses commercial value.

A two-cylinder compound can be put to any simple engine, for less cost than any other type, and in doing so will replace and require the least number of working parts. The altering of existing simple engines into two-cylinder compounds, is thus made altogether feasible, and the building of new ones can be done at a cost very little over simple ones of same type and power.

The Rhode Island Locomotive Works improvements solve these problems perfectly. They furnish a locomotive that, for any time and service is at once simple or compound—an accomplished fact which your committee believes has not been done before in any country.

A great number of two-cylinder compounds, having the Worsdell von Borries type of valves and steam-ways, have been made, and are now running with good economical results.

If, therefore, the two-cylinder type of engine is so well favored, as those referred to, which are limited to certain kinds of traffic, adapted to the special construction of these engines, how much more will the same type be valued when it is suited to every service, by being perfectly interchangeable, with full range of performance, either as simple or compound.

Your committee recognizes the fact of greater value in accomplished results by the manufacture and completion for active service of any machine.

An inventor, who, after conception of his scheme, builds it, puts it into service and proves it to have commercial value, is entitled to advanced credit at our hands for having done more than merely invent and patent.

We make this statement here because we find on investigation that not

one-half the number of compound locomotives, which have been patented and described have ever advanced beyond the patent record and not one-quarter of them are placed upon the roads in service. Many of us know by experience that some patented machines are not even well begun with the issue of the patent.

During that noted controversy upon the discovery of the expansion of steam in Watt's time, a writer said: "Of two discoverers of the same principle, that one should have the merit, who first makes it known to the public."

To this type of expression, may be justly added: A large need of praise and right-of-way belongs to the party who harnesses a discovery by whomsoever made and puts it under full control to do our bidding. Nor should the mere patented or other existence of any invention in one original form (which may yet be within experimental limits), forbid the use of its like conceived by another although in modified form, when the same has been adapted and carefully fitted to new working conditions. In this the last shall be first by merit.

"The conditions on which the expansive working of steam in locomotives may be carried out with efficiency and success were stated by Mr. D. K. Clark, as early as 1852, in *Proc. Inst. M. E.*, for that year and briefly are as follows:

(1) The condition is to perfectly protect the cylinders.

(2) The combination of a sufficiently high boiler pressure of steam, (say) 150 pounds per square inch, with suitable proportions of cylinder and driving wheel, to admit of highly expansive working consistent with the required duty of the engine.

(3) The cylinder should be arranged to have the shortest practicable steam-way, and the valves should be relieved of pressure.

From Mr. D. K. Clark's latest, most elegant and comprehensive work on *The Steam Engine*, London, 1890, vol. iv, p. 603, we make a few extracts, which, on perusal, will be found to emphasize much that we have already said upon the compound locomotive.

"M. Anatole Mallet had early prepared designs for compound locomotives, in which one of the cylinders was made larger than the other; and in the beginning of 1876, an order was given for three of them. They were four-coupled six-wheel tank-engines, with two outside cylinders, 9·45 inches and 15·75 inches in diameter, with a common stroke of 17·72 inches, having areas in the ratio of 1 to 2·78. The working pressure in the boiler was 150 pounds per square inch."

"The 'starting slide valve' was fixed on the smoke-box, by means of which the steam from the first cylinder might, at starting, be exhausted direct into the atmosphere, while steam from the boiler was admitted direct into the second cylinder, sufficiently wire-drawn to avoid an excessive difference of power between the two cylinders. When the valve was shifted into the opposite position the steam from the first cylinder was exhausted to the second cylinder. The engines were first tried in July, 1876; they made steam in abundance, and worked with perfect steadiness."

See Mallet's paper "On the Compounding of Locomotive Engines," in the *Proc. Inst. Mech Engineers*, London, June, 1879, p. 328.

To M. Anatole Mallet belongs the credit of first realizing the necessity of equalizing the total pressure of the steam in each cylinder of a compound locomotive engine, especially in those of a large size.

In his paper he describes "a *self-acting reducing valve*, whereby the steam pressure admitted to the large cylinder when working direct is reduced so as never to exceed a certain limit bearing a constant proportion to the boiler pressure."

This valve consists of "a piston having a rod of large diameter, which passes out through a stuffing-box at the back end and has no external attachment." The piston acts as a stop-valve sliding over a port at the back end," which opens and *partially closes* before and after the admitted steam to the starting-valve chamber. This valve was not provided with any means whereby its motions would be controlled, and, therefore, was liable to breakage from violent slamming, which was proven to be the case on the first trials of those made, the record of which appears in his paper on this subject.

We find no reference of attempts to improve or continue the use of this type of valve.

"Mr. A. Borodine, Chief Engineer of the Southwestern Railway of Russia, made comparative trials of a compound passenger locomotive on the Mallet system and an ordinary locomotive. The engines were identical, except the cylinders; they were tried on a section ninety-seven and one-half miles long, in the month of May, 1881. The results of twelve double-trips show an economy of steam of from four to eight per cent.; and of fuel, of from fifteen to eighteen per cent." "In July, 1881, the two engines took goods trains exactly alike, one to each, one after the other, at speeds considerably lower than those of the passenger trains, showing an economy of thirty per cent. in the consumption of steam by the compound engine and of twenty per cent. of fuel." "Further, experiments with these engines showed an economy of fuel of twenty per cent., with 2·5 expansions of the steam and thirty-two per cent. with 4·8 expansions." See *Proc. Inst. M. E.*, London, 1886, p. 297.

Mr. Clark devotes one chapter to a discussion of the Von Borries outside cylinder compound locomotive, in which he concludes: "Compared with ordinary engines of like dimensions, working on the same lines and taking the same trains, the compound locomotives effect an economy of from 14·3 to twenty-one per cent. of fuel." See *Engineering*, April 30, 1886, p. 434.

In his next chapter Mr. Clark says: "Mr. T. W. Worsdell, in 1885, designed and constructed his first compound passenger locomotive for the Great Eastern Railway, in which two cylinders were employed, placed side by side, between the side plates. The cylinders are eighteen and twenty-six inches diameter, twenty-four inches stroke, working to the crank-axle in the usual manner; the capacity-ratio of the cylinders is 1 to 2·09. The engine fitted with Joy's valve-gear and steam could be turned on direct to the second cylinder when required for starting."

The performance May 21, 1886, showed "a reduction of thirteen per cent. on the ordinary consumption."

"In January and February, 1888, comparative trials of compound and ordinary passenger locomotives were made on the Northeastern Railway, which proved a saving by compound engine of twenty-one and one-half per cent."

"In the year 1886–87, the comparative consumption of coal, by compound and ordinary goods engines working heavy express trains, was for ten engines each, and making a total run of 186,000 miles, a saving of fourteen and one-half per cent."

"There are now (April, 1890), about 600 compound locomotives on the Worsdell and Von Borries system, of which there are 120 on the Northeastern Railway. The average results of twelve months' working of these 120 engines, compared with the non-compound engines on the railway, drawing the same trains, 150 tons weight, show an economy of twenty-two per cent. of coal."

Mr. Thomas Urquhart, on Railway in Southeast Russia, has ascertained an average economy of eighteen and one-half per cent. of petroleum refuse in the performance of twelve compound goods engines and three compound passenger engines, as against non-compound. The capacity of the receiver between the first and second cylinders, has been successively increased from equality to the volume of the first cylinder to 1·3 and 1·8 times, with marked advantage. The pressure in the second cylinder does not drop so fast with the larger receiver." See *Proc. Inst., M. E.* London, 1890.

The early state of the art shows that ordinary cocks and slide and other forms of valves operated by the engineer have been used for admitting steam to the low-pressure cylinder directly from the boiler for starting the engine, to be operated again by the engineer, changing the engine to compound running when the extra resistance is overcome, some having independent escape to the atmosphere for the high-pressure cylinder, and some have closed exhaust chambers.

The *advanced state of the art* exhibits the use of valves in the high-pressure cylinder exhaust pipe or receiver, which are worked by steam automatically or otherwise.

The greater number of these valves are opened automatically by the high-pressure cylinder exhaust steam when its accumulated pressure exceeds that of the admitted wire-drawn live steam to the low-pressure steam chest. These are called intercepting valves, and no means are provided for holding them shut for continued simple running.

Your committee plainly sees that any engine, exhausting into a closed chamber must weaken after the first revolution, and must gradually cease to have power if this process continues, and that this effect happens just at the time when the greatest power is needed; and again when this chamber gets relief, the engine at once ceases to be a simple engine, and goes into compound working. If the engine has not got under way by this time, it must balk and simple running be tried over again.

In the specification of F. W. Dean (U. S. Patent, Sept. 22, 1891) mention is made of the fact of accumulated pressure in the high-pressure exhaust passage, and the necessity of relieving the same. It is also stated: "The intercepting valve opens in advance of an accumulated back-pressure on the high-pressure cylinder," so it appears that some inventors recognize this fact of back-pressure where and when it is not wanted.

The *perfected state of the art* must exhibit a two-cylinder compound locomotive engine whose mechanism is simplest in form and number of working parts, and whose steam ways are most uniform in section and most direct in course from boiler to the point of application.

In so far as your committee has ascertained from every reliable source at its command, the mechanism devised by Mr. C. H. Batchellor practically fulfils this requirement.

In this engine we have all the necessary devices by which a locomotive may be run at any time and at any place on the road and for any length of time demanded by the service, as a simple engine; each cylinder doing exactly half the work, whatever that may be, and without waste of steam.

In addition to this, at the will of the engineer and at any time he chooses to exercise it, according to the conditions of running, he changes his engine into compound working, permitting it to operate thus as long as circumstances will warrant, and then he changes it back again at once into simple working. These changes are made as easily as the engineer turns his hand to open or close *one* valve, by a handy lever in his cab, and he does this when the engine is standing or running.